A Clinical Study of Poisoning by Coal Gas During the Decade 1938 - 1948

by

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"EVERY physician will make, and ought to make, observations from his own experience; but he will be able to make a better judgement and juster observations by comparing what he reads and what he sees, together. It is neither an affront to any man's understanding, nor a cramp to his genius to say that both the one and the other may be usefully employed and happily improved in searching and examining into the opinions and methods of those who lived before him....."

FRIEND, HISTORY OF PHYSIC,
Volume 1.

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INTRODUCTION.

Throughout the British Isles there can be few hospitals with a ward serving so large a population as the detention ward of the Royal Infirmary of Edinburgh. Practically all cases of poisoning occurring in the South Eastern Region of Scotland pass through this ward, and it was this unique feature which prompted me to inquire more closely into the large group of patients poisoned by coal gas either by accident or by intent.

With interest stimulated and reading widened, I realised that poisoning by gas still presented many problems; what was fact to one author appeared apocryphal to another; the problem as to whether the toxicity of illuminating gas was due to a pure anoxia or to a toxaemia; the frequency of sequelae and their relation to accidental and to suicidal poisoning, particularly in the subclinical types; the effective treatment and the Public Health problems associated with the subject; the known but as yet ignored increase in the accident rate due to coal gas poisoning over the last ten years, and whether some more lasting and more definite identification could not be introduced into the gas to safeguard the public.

As light was shed more clearly on some problems, others presented their diverse shapes, and these I attempted to clarify both by reference to experimental and clinical studies embracing the years 1938-1948.

Historical

In 300 B.C. Aristotle made the acute observation that exposure of man to coal gas caused heaviness in the head and even death.

Hitler's extermination chambers were copies of such acts of revenge as were first conceived by Hannibal when he put to death the inhabitants of Nucerii, in 47 B.C.

In 68 A.D. Seneca after many unsuccessful attempts at suicide finally killed himself after prolonged inhalation of charcoal vapour.[38]

In the middle of the 3rd century, Aurelianus described disturbances of movement and sensation,[174] following gas poisoning.

As the years have gone by, coal gas has been more and more used as a source of light, heat and power in the home and in industry. Thus, its availability and universal use largely account for the increase in the numbers poisoned by the gas.

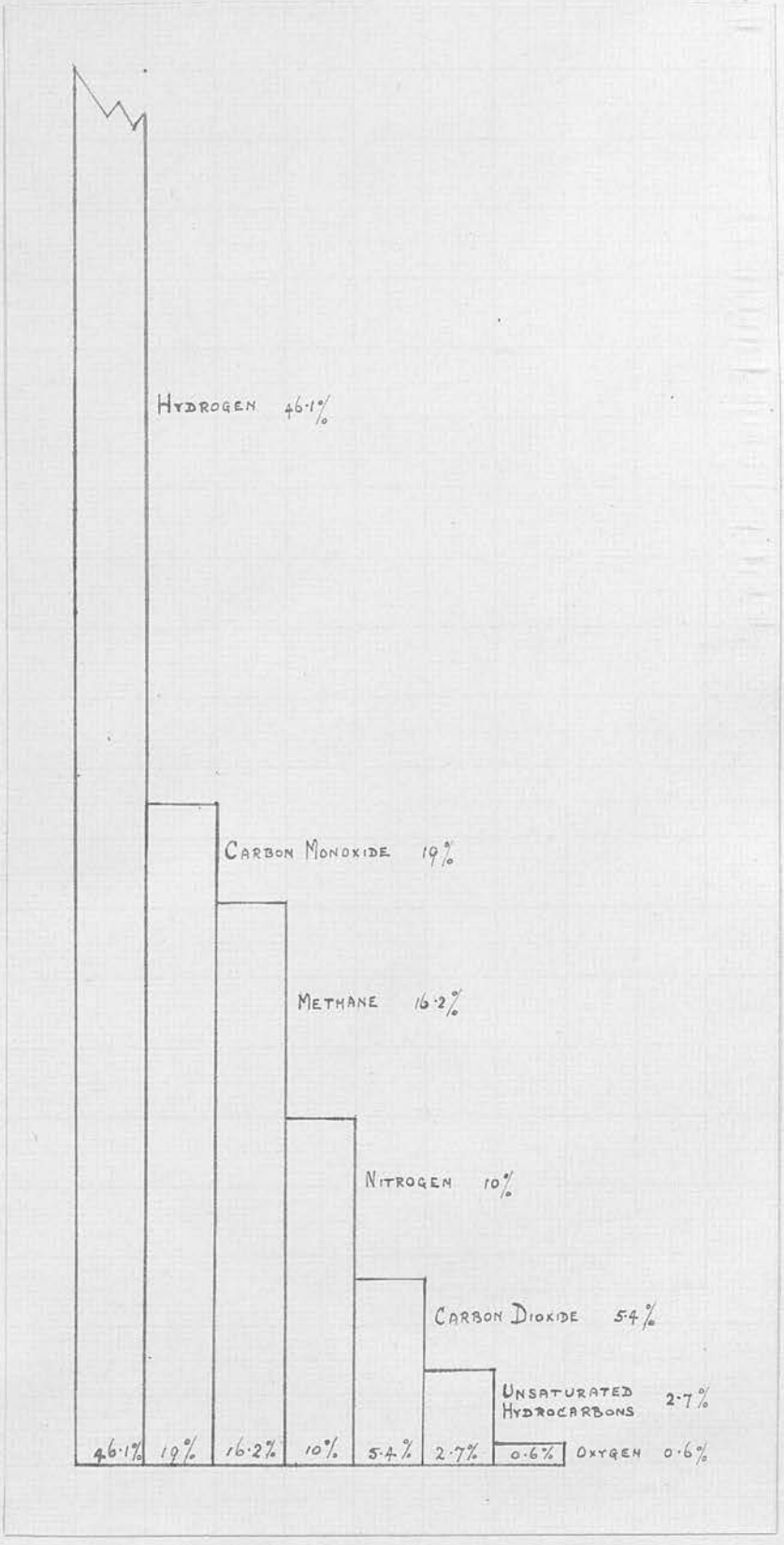
Properties

Illuminating or coal gas, as now supplied to the domestic consumer, is manufactured by destructive distillation of coal. During the decade under review from 1938-1948 an analysis of the percentage constituents was as follows:[186]

Carbon Monoxide	19%
Methane	16.2%
Carbon Dioxide	5.4%
Unsaturated Hydrocarbons	2.7%
Hydrogen	46.1%
Nitrogen	10%
Oxygen	0.6%

In/

Table 1.



Percentage Constituents of Coal Gas (Scotland). 1938-1948.

In some areas, water gas and producer gas are supplied in lieu of coal gas, the former containing as much as 30% carbon monoxide while in the latter the percentage of carbon monoxide is lower, being between 20-30%.

In industrial plant carbon monoxide is liberated (for electrical furnaces have limestone linings and the carbon dioxide is reduced to carbon monoxide). In poorly ventilated stoves, in Indian charcoal Segris, in distillation of oil, gas engines, fumes from explosions and in mines, carbon monoxide may be liberated with disastrous effect. Even nearer to the home - the low burning oil lamp may give off a not inconsiderable percentage of carbon monoxide, while in lesser degree, cigarettes, when inhaled, can produce in the blood stream, 0.01 - 0.26%, cigars 0.027 - 0.15 % and pipe tobacco 0.27%.[168]

When pure, carbon monoxide is practically insoluble in water, and is a colourless, tasteless, odourless gas. This latter property makes it a source of poisoning in industry, for it is the hydrocarbon impurities in illuminating gas which give it its distinctive odour.

Carbon monoxide, in comparison with air, has a density of 0.967, and it can be compressed into both liquid and solid form. When burning, 2 volumes of carbon monoxide combine with 1 volume of oxygen to form 2 volumes of carbon dioxide.

When/

When carbon monoxide comes into contact with the blood it unites with the haemoglobin to form carboxy-haemoglobin (COHb) exactly replacing the oxygen, volume for volume. According to Douglas et al one volume of carbon monoxide acts like 220 volumes of oxygen, as the carbon monoxide has an affinity for haemoglobin 220 times that of oxygen, but the red blood cells are not dead, and in order to restore the natural physiological process, all that is necessary is oxygen of sufficient tension to replace the carbon monoxide.

Barcroft[13] showed that carbon monoxide enters into combinations with blood more readily when oxygen is present than when oxygen is completely absent. It is possible, however, that the oxygen deprivation causes increased circulation time with a more rapid absorption of carbon monoxide into the alveolar blood. The whole blood volume is not saturated with carbon monoxide, for the splenic pulp has been shown in the experimental animal to be free from carbon monoxide. In other words, there must be either:-

(a) a barrier, excluding circulating red blood cells from the pulp.

or (b) a by-pass mechanism which excludes the contaminated red blood cells from the splenic pulp.

The therapeutic possibilities of such a reserve of normal red blood cells are obvious, and are discussed more fully in Chapter VI.

The natural consequence of the formation of carboxy-haemoglobin is to deprive the tissues of oxygen/

oxygen, and Haldane and Haggard both maintain that symptoms and signs of coal gas poisoning are due to anoxia, the symptoms increasing with the degree of saturation of the blood.[98] Death, they conclude, is therefore due to a failure of respiration of the nature of a fatal Apnoea Vera. This respiratory failure is accentuated in those deeply gassed by excessive breathing due to anoxia, which in its turn induces an abnormal loss of carbon dioxide.

My experience bears out this theory, for I found in my series of cases that a patient who is subjected to a sudden high concentration of coal gas, e.g. a suicide who places his head in a gas oven, develops respiratory failure due to oxygen deprivation as surely as one does who has been submerged in a bath of water.

Animal experiments with mice showed that an exposure to between 200 and 300 times the fatal dose of carbon monoxide was necessary when given in the presence of one to two atmospheres of pressure.[99] It is known that respiratory failure may be prevented by the administration of 8-10% of carbon dioxide, the carboxy-haemoglobin combination rising to an unusually high percentage.

There is a hypothesis that gas poisoning is more than a simple asphyxia, that there exists a toxic effect which has a specificity for vital nerve centres and by so damaging them, causes death or untoward sequelae.* References to the late effects of/

* 197, 88, 54, 94, 93, 104, 129, 121, 76, 97, 109,

of coal gas poisoning occur frequently in the neurological literature* representing the gross clinical entities which are readily recognisable but there is little mention of the border line cases, the indefinite ills and so called neurosis which abound when looked for in our increasingly carbonated milieu.

* 190, 201, 218, 118, 82.

TABLE 2.

Atmosphere to which Nervous tissue exposed.	Nos. of Cultures.	Nos of Growths.	% Growth.	Remarks.
Atmos. Air	36	31	86.1	Growth normal in appearance.
79% CO; 21% O_2	20	18	90.1	Growth normal in appearance.
Coal Gas + Atmos. Air.	18	0	0	Tissue dead and partly disintegrated.

To show the reaction of chick nervous tissue in the presence of air, carbon monoxide and air with .1% coal gas.

Haggard, H.W., (1922)
Am. J. Physiol. 60, 245.

COAL GAS AS A SELECTIVE NEURAL TOXIN.

Haggard,[97] in 1922, compared the growth of nervous cells outside the body, in:-

(1) Air.

(2) 79% carbon monoxide and 21% oxygen.

(3) 0.1% coal gas and 99.9% atmospheric air.

The coal gas which he used had the following composition:-

carbon monoxide	21.4 %
methane	19.8 %
hydrogen	43.2 %
olefines	5.6 %
nitrogen	5.1 %
oxygen	4.0 %
carbon dioxide	3.5 %
benzol	1.0 %

Nerve tissue grew in the carbon monoxide/oxygen mixture, showing that, with adequate oxygen, the tissue remains viable in pure carbon monoxide, on the other hand, no successful growth of nerve tissue was obtained in the mixture of atmospheric air lightly diluted with coal gas. Since this mixture obviously contains only small amounts of carbon monoxide, there must have been some other reason for the inhibition of growth, some accessory factor which in vitro conditions is highly toxic to growing nerve cells. (Table 2.) Haldane confirmed these figures by showing that cockroaches which possess no haemoglobin, may be kept alive for several/

several weeks in an atmosphere of 20% oxygen and 80% carbon monoxide.[100] Yet the movements of a moth and germination of cress were inhibited by carbon monoxide.[99]

In other experiments, Henderson[100] concurred with the above findings. He found that comparing coal gas with carbonic oxide (made from formic acid) death occurred in the former case when the concentration reached 65% saturation whereas with the latter, death occurred at a blood saturation of 85%. Coal gas, therefore, owes 20% of its toxicity to some substance other than carbon monoxide. Henderson et al. subjected dogs to concentrations of carbon monoxide gas 0.3 - 0.4 % in various gases with varying concentrations of oxygen; the following results were obtained which have a direct relationship to their human counterparts:-

(a) <u>With pure carbon monoxide + air</u>
The animals became unconscious with no more apparent discomfort than if anaesthetised with ether. The blood of five dogs at the point of death contained the following percentages of carbon monoxide: 87, 82, 84, 70, 88, i.e. average of 84%.

(b) <u>With coal gas + air</u>
In such absorption, the symptoms during intoxication differed in some respects from the preceding group. There occurred in all cases more rapid collapse and distinctly greater respiratory excitement. Nausea and vomiting which were lacking in experiment (a) occurred in all animals of the second group (b) and death ensued at a lower percentage of carboxy-haemoglobin concentration, indicating that there was some extra toxic substance rendering it more harmful than an equal amount of pure carbon monoxide. The average was 70%.

(c) /

(c) With exhaust gas from a petrol engine + air.
This mixture containing approximately the same concentration of carbon monoxide as in experiment (a) was administered to the dogs. The symptoms were similar in all respects to experiment (a) and the percentage carboxy-haemoglobin at death averaged 83%.

(d) Exhaust gas from a car using coal distillate + air.
The dogs so exposed to a similar concentration of gas as in previous experiments reacted with symptoms as in experiment (b), and died with symptoms similar but more marked than those poisoned with coal gas. Average at death 62%.

These results show that, experimentally, there is a higher toxicity from inhaling coal gas and air, and fumes from coal distillate, than from pure carbon monoxide from petrol exhaust.

In 1930 it was shown that when human red blood cells were exposed to carbon monoxide, coal gas and exhaust gas, and then tested for fragility, the effects were more severe in the case of coal gas; car exhaust was less damaging and carbon monoxide had no effect at all.[157]

Ford was unable to obtain brain lesions in cats or kittens by the asphyxiants chosen from various types of experimental asphyxiants. Cerebral lesions were not produced with pure carbon monoxide but when coal gas was used the pallidal lesions were found. Finally, in 1942, again in animal experiments, it was found that where the concentration of carbon monoxide and benzene exposure along with the temperature were noted, neither carbon monoxide alone nor benzene alone caused marked mortality but when animals were exposed/

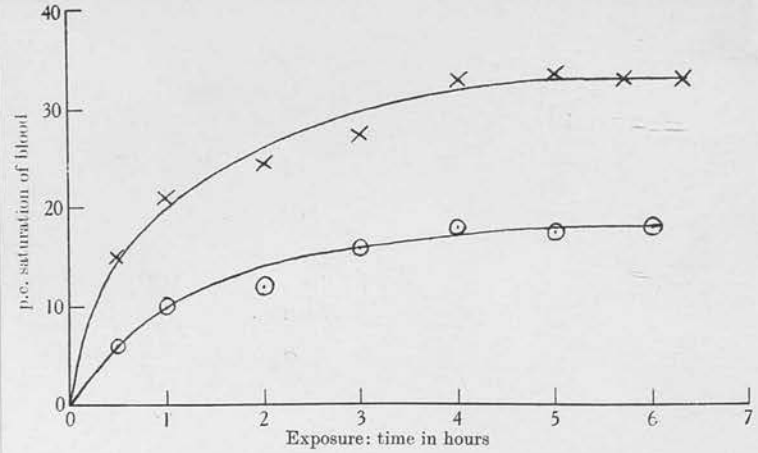
exposed to the two together, the combined toxic effects were fatal.[39]

Experimentally, cortical and pallidal necrosis was caused in dogs when exposed to repeated concentrations of 0.01% coal gas which led to a saturation of 20% carboxy haemoglobin approximately. From these experiments it was concluded that changes in the organs depend, not on the concentration of the carbon monoxide in the blood, but on the length of time of exposure even to small quantities of the coal gas.

Two cases of death were reported following poisoning from a wood stove. Both brains showed more or less diffuse degeneration of the white matter and marked progressive changes in the glial cells and patches of demyelination. There was no bilateral softening of the globus pallidus.[118]

In the decade under review only one patient, Mr. G. aged 43, suffered poisoning from inhalation of car exhaust. He succumbed and at post mortem the meninges were congested but there was no evidence of damage to the globus pallidus. It is also a recorded fact that since the Holland Tunnel in New York came into being there is no recorded case of a Traffic Officer working there, suffering from any ill effects due to chronic exposure to petrol engine exhaust. Yet these 156 Officers were intermittently inhaling from 0.02% - 0.03% carbon monoxide daily.[181] It is obvious that in these experimental and clinical cases cited above, carbon monoxide was present in greater/

Plate I.



Saturation of the blood with CO during exposure to 0·023 p.c. CO.
Before acclimatization: 14. ii. 34, × After acclimatization: 9. x. 34, ⊙

Acclimatisation to Carbon Monoxide.

greater or smaller amounts but what differed were the other constituents.

Killick[122.] showed in both human and animal experiments that acclimatisation could be readily produced with lessening of symptoms during increased exposures to the same concentration of carbon monoxide. This would argue in favour of carbon monoxide poisoning being more complex than that of a simple asphyxiating agent for there is no evidence of a sufficient compensatory increase in the oxygen carrying power or in the red blood cells to account for this phenomena. We know that apart from its anoxic effect, it is now recognised that carbon monoxide has histio-toxic properties inhibiting the tissue enzymes[25.], but these properties have little practical bearing in man for by the time the concentration is reached the cells have already been rendered non-viable by virtue of anoxia. It is evident, therefore, that the direct anoxic action of carbon monoxide does not account for the signs and symptoms produced in coal gas poisoning. Anoxia alone is not wholly embracing, and cannot explain this constant involvement of the globus pallidus and the predilection for neural parenchyma. Surely, therefore, a second "agent provocateur" is present in coal gas as generally supplied to the public, which has a selective action for neural tissues, and which can cause cumulative damage.

Clinically, the very fact that the victim with neurological sequelae does not need to have been previously/

NAME.	CASE NO.	PATH. FINDINGS.
Mr. W.R.	121	Pallidal Necrosis and Pallidal Siderosis.
Mr. W.G.	326	Globus Pallidus Infarction.
Mr. D.T.	538	Bilateral Pallidal Necrosis.
Mr. T.H.	437	Bilateral Pallidal Necrosis and Siderosis.
Mr. J.B.	113	Bilateral Pallor with Ischemic Necrosis of Left Globus Pallidus.
Mrs. A.M.	328	Bilateral Infarction Globus Pallidus.
Mrs. A.H.	114	Bilateral Ischemic Infarcts of Globus Pallidus with Pallidal Siderosis.
Mr. T.T.	511	Bilateral Softening Lenticular Nucleus.
Mr. F.H.	525	Bilateral Necrosis of Globus Pallidus and Pallidal Siderosis.

Random Sample of Path. Reports
From this Series.

Total number of cases	32
Hyperemia of the brain and leptomeninges	29
Edema of the brain	21
Petechial hemorrhages in leptomeninges and white matter	15
Arteriosclerosis and vascular degeneration in advance of age of patient	19
Necrosis of the lenticular nucleus evident as gross softening	14
Lenticular degeneration found microscopically	32

Hill E., Semerak C.B. quoted by Drinker C.K.
Carbon Monoxide Asphyxia.
1938 p. 132.

previously rendered unconscious, is in agreement with this theory, and is against anoxia being the only aetiological factor. This is illustrated by the case of Mr. J.H., discussed in Chapter VII, who had been exposed only intermittently to low concentrations of coal gas over many years and the only evidence of gassing was that there were occasions when he felt light-headed and dizzy, symptoms which rapidly subsided in the fresh air. On no occasion had this man become unconscious although he finally developed the full picture of Parkinsonism.

It is clear that little thought has been given to the other constituents of coal gas, yet from the literature it can readily be seen that with poisoning from coal gas there is a variation in constituents of gases from different areas and in the quantity inhaled, which could account for the diversity of sequelae both with regard to their location and constancy. It is interesting to note that in 1914 a Report of the Departmental Committee on Compensation for Industrial Diseases[175] stated that very little seemed to be known of neurological sequelae following gassing in mines, for only four cases had been found, two by Sir T. Oliver[164] and two by Dr. Judson. The paucity of neurological sequelae in coal mine explosions was also commented on by Denny-Brown[55] and by Glaister & Logan. Again, at a later date following the major disaster in the Fife Valleyfield Colliery,[172] it was evident that neurological lesions were in abeyance for,/

for, almost to a man, the victims suffered from cardio-vascular symptoms. It is obvious, however, that for each explosion the constituents of the explosive gas will alter with each pit. Glaister & Logan quoted some Colliery disasters as having as much as 8% carbon monoxide with, of course, varying concentrations of methane, carbon dioxide, nitrogen and the unsaturated hydrocarbons, and I believe that the varying percentages of the explosive gas account for the diverse nature of sequelae.

The ordinary motor engine with carburetter adjusted to give a fuel/air ratio of 1/12 produces an average of:-

7.9% carbon monoxide.
0.2% methane.
8.9% carbon dioxide.
4 % hydrogen.
78.8% nitrogen.
0.2% oxygen.

The gross difference, comparing these figures with the Table 1, is seen in the methane and hydrocarbon percentages, which, in petrol exhaust, are infinitesimal unless the carburetter becomes "dirty". This accounts for the symptom free state of Traffic Officers. It is quite feasible, therefore, that differences in the percentage constituents of the noxious gases viz. methane and the other hydrocarbons, along with the damaging effect of anoxia caused by carbon monoxide, are responsible for the damage to the/

the central nervous system with the constant vulnerability of the globus pallidus. From personal observations this specific effect seems to be dependent on the concentration of oxygen available to the tissues... If poisoning occurs very quickly, oxygen deprivation is fast and the victim succumbs to asphyxia, whereas, if the gassing is slow or intermittent, the toxic substance in an area already compromised by anoxia would cause further damage and sequelae would result. Naturally there will be gradations of poisoning both with regard to respective percentage constituents and length of exposure, so that the so-called "Acute" case of poisoning may show neurological sequelae and a "Chronic" poisoning no ill effects whatsoever.

Lack of correlation between gassing and activity during exposure is noticeable in the literature by the complete lack of comment. In the acute case of poisoning, usually the suicide, it is performed secretly, either lying on a bed or on the floor at complete rest, as in cases cited on Page 94, but in accidental poisoning, usually the chronic case where the victim is exposed while engaged in active movements, he suffers from severe neurological sequelae if successfully resuscitated, as opposed to mental sequelae in the acute case. The former is inhaling the gas at a resting metabolic rate while the other does so during active metabolism. This unknown toxin is acting in an area where there is altered/

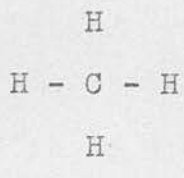
altered cell respiration and the cells are in a state of active metabolism.

From the Table I , the next highest constituent to carbon monoxide is methane. Methane is an odourless member of the aliphatic hydrocarbons and present in natural gas up to 85%. It is reported by standard text books as having no appreciable physiological action, unless the lowering of the partial pressure of oxygen in the air is great enough to cause anoxia. In the vapour state these paraffins are mildly irritant to the mucous membrane, increasing in intensity as the molecular weight increases, as in a similar way does its toxicity. They all produce, however, a simple anaesthetic action affecting the central nervous system.[98] Although this anaesthetic action has been recognised, its mechanism is still obscure and there are many conflicting theories. What has not been ascertained is whether, when methane is inhaled, it is exhaled in its entirety, unchanged. Lussem[135] has demonstrated that, where a large percentage of methane is present, a stupefying effect is produced.

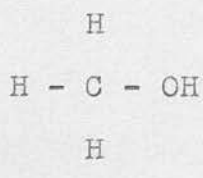
> "When animals breathe large quantities they become sleepy, while on men it has a stupefying effect. Recovery is rapid in fresh air".

Attending to cases of gas poisoning, I have noticed the similarity in the early stages to alcoholism; this difficulty in differential diagnosis has/

has been previously commented on.[32] The formula of methane is:-



Should one of its molecules be hydrolysed this would give the toxic substance - methyl alcohol.



This is difficult to perform in vitro but it might well take place in vivo, for a similar action which is impossible to perform in vitro takes place in the body when the benzene ring is split.

This substance, methyl alcohol, has properties of high toxicity; the toxic dose and symptoms vary greatly, being extraordinarily enhanced by impurities. This knowledge was gained during the bootlegging days of prohibition in the U.S.A. and following poisoning cases in this country. Therefore, if methane is converted in the body to methanol, it might well be excreted in the urine as formaldehyde and formic acid, for it is generally agreed that 40% is slowly oxidised to formic acid, 20% exhaled, 30% excreted as such in the urine or oxidised to formic acid; one-third remaining forty-eight hours after ingestion.

Formic acid, this end product of methanol matabolism, is excreted in the urine and reduces Fehling's solution. Glycosuria is a sign not infrequently/

infrequently found during recovery from coal gas poisoning and thought by Leschke[130.] to be due to a disturbance of the regulating centres in the brain stem - "otherwise it would hardly pass so quickly". Ziesche[223.] and Rogers[178.] in fact, quote only a single case of permanent diabetes resulting from coal gas poisoning. Evans[72.] discovered that in rats kept at a pressure of half an atmosphere of air, the liver glycogen increased. This occurred even if they fasted. Similar experiments have now been made on experimental animals suffering from anoxia due to carbon monoxide poisoning. The very fact that some cases were reported with glycosuria three to four days following the gassing attack was against anoxia being the sole cause.[182.] Schulze, using mice, came to the conclusion that the immediate effects on the blood sugar and liver glycogen were ascribable to the action of asphyxia on the adrenal glands, but that the thyroid was responsible for the later or more enduring effects. It is true that in experiments on cats and rabbits the chromatin substance in the medullary layer of the suprarenal capsules disappeared and also the colloid masses of the follicles of the thyroid gland.[208.] This was followed later by increased formation of the colloid. There is great doubt, therefore, as to the cause of glycosuria. Although no case of glycosuria occurred in this series of cases, I would suggest that the breakdown of methane may be responsible for the reduction/

reduction of Fehling's solution and as such, may give a false diagnosis of glycosuria and therefore, urine should be tested with Benedict's solution.

Symptoms produced by methyl alcohol would be mild in comparison with those occurring following the ingestion of wood alcohol. As is true of all poisons in which lipoids are soluble, the brain is found to retain more of the alcohols than any other organ. This fact, together with the delay in oxidation, explains the symptoms of poisoning which are common only to this alcohol. Repeated small doses may be more harmful than a single large dose. Symptoms described range from gastro-intestinal upsets, general weakness and vertigo to fogginess of vision.[224] I believe that this aliphatic hydrocarbon may be responsible for many of the ill effects of coal gas.

The unsaturated hydrocarbons found in coal gas cover a mixture of substances largely made up of ethylene, benzene, xylene and smaller quantities of propylene, butylene, and acetylene.[187] As far as is known both ethylene and acetylene are simple asphyxiants but act also as anaesthetics when inhaled. The latter gas does possess known toxic properties and is described as "moderately poisonous" in respect of industrial hazards. A concentration of 100 mgm/litre may be tolerated for 30-60 minutes. It can readily be seen that these gases are similar in their action to the homologues of methane (ethane, propane and butane). I am interested/

interested in them, for it is known that they are absorbed through the alveolar membrane into the blood stream - their anaesthetic effect proves this. Their effect in a short, sharp attack of gassing would be asphyxia, but their action in small concentration is unknown - the analogous condition to chronic coal gas poisoning. Perhaps they are stored in the liver similar to the carbon molecule in carbon monoxide poisoning.

Of the aromatic hydrocarbons, benzene, toluene and xylene are the commonest constituents present. It is pertinent to remark that in the experimental literature concerning these substances the addition of xylene and toluene to benzene did not increase its toxic effects.[203] In general, the signs and symptoms of benzene poisoning are faintness, dizziness, weakness and headaches with visual disturbances, tremor, collapse and mania which may precede death.[118] On other occasions death occurs several days subsequent to exposure. In chronic poisoning its effect is felt in the blood forming organs and destruction of the blood cells. In one experimental group with small concentrations of benzene no marked changes were noted in the blood picture of dogs, although urine studies indicated absorption and elimination of benzene. In the experiments quoted above and later confirmed by Heiztman[106] it was found that the spleen contained an increased deposit of haemosiderin. Others confirmed this finding in human victims.[143] The origin/

origin of this iron may be from cell nuclei or red blood cell corpuscles.

It may be remembered from Chapter II that carbon monoxide produces no effect on red blood cells. If, however, hydrocarbons such as listed above are added, immediately a pathological change takes place in or on the red corpuscles with liberation of iron; similarly, it has been shown that animals succumb to a much lower concentration of the mixed gas than with pure carbon monoxide. This extra factor, contained in coal gas, be it saturated or unsaturated hydrocarbons, may interfere, in some way, as yet unknown, with the oxygen carrying power of the red corpuscles or with the nerve cell. Experimentally, it is possible for them to enter the general circulat-:ion; further elucidation as to the nature of storage or tissue vulnerability is awaited. The fact remains that whether saturated or not, hydrocarbons seem to be the malicious associates of carbon monoxide. From our present knowledge it is readily seen that the toxic effects accruing from the individual hydrocarbons are not, in themselves, sufficient to produce the known sequelae but when acting in association they constitute the extra toxic factor which is responsible for the sequelae of chronic poisoning.

Plate III.

TISSUE	SURVIVAL TIME IN MINUTES
Cerebrum, small pyramidal cells	8
Cerebellum, Purkinje's cells	13
Medullary centers	20–30
Spinal cord	45–60
Sympathetic ganglia	60
Myenteric plexus	180

Compiled by Drinker, C.K.
(Carbon Monoxide Asphyxia p.133).

THE ABILITY OF CENTERS AT VARIOUS LEVELS OF THE NERVOUS SYSTEM TO WITHSTAND COMPLETE INTERRUPTION OF BLOOD SUPPLY *

INTERRUPTION OF CENTRAL CIRCULATION UP TO:	REVIVAL OF CENTERS				
	CORTICAL	PALPEBRAL PUPILLARY	CARDIO-REGULATORY	VASOMOTOR	RESPIRATORY
1– 5 min.	+	+	+	+	+
5–10 "	–	+	+	+	+
10–15 "	–	–	+	+	+
15–30 "	–	–	+	+	+
> 30 "	–	–	–	–	–

* Tabulation made by Dr. Heymans and presented to author. Data largely contained in Heymans, Bouckaert, Jourdan, Nowak, and Farber (1937).

Anoxia and Survival Times of Nervous Tissue.

Chapter 111.

THE PATHOLOGICAL EFFECT OF COAL GAS IN COMPARISON WITH OTHER ASPHYXIANTS.

The low threshold of cerebral tissue to anoxia is well known; suffice it to say that cortical tissue shows no recovery, if it is deprived of oxygen for more than five to eight minutes; the medulla, twenty to thirty minutes and the spinal cord, forty-five to sixty minutes as shown in Plate III compiled experimentally by Drinker. The processes most recently acquired are affected first and as the anoxia progresses the depression spreads to the coarser and earlier developmental centres.[38,102] This has a profound significance in coal gas poisoning for the intellect becomes dulled without the victim being aware of it, the power of memory is early affected and is finally almost annulled, so that even persons not losing consciousness can nevertheless remember nothing of what has occurred. Powers of sane judgement are much impaired and anaemic persons become subject to more or less irrational fixed ideas and to uncontrolled emotional outbursts. Without reason the victim begins to laugh, shout, sing, burst into tears or become desperately violent. He is, however, quite confident that he, himself, is perfectly sane and reasonable although he may notice that he is unable to walk or write properly, and cannot remember what has just happened nor properly interpret his visual impressions. Even Haldane,[101] whilst experimenting on himself with carbon monoxide poisoning or anoxia produced by low pressures in a steel/

steel chamber was always confident of his own sanity and it was only afterwards that he realised he could not have been in a rational state of mind. In effect, the person deprived of oxygen may be brought to the verge of unconsciousness without realising his peril in the least degree. Muscular weakness, too, is a prominent feature and occurs so early that it is not thought to be entirely produced through the central nervous system. These symptoms constitute the main barriers in the prevention of gas accidents.

It is stated[137] that in a pure anoxia there is no significant alteration in behaviour until the diminution of oxygen reaches fifty per cent of normal. When mountain sickness occurs[12] the comparative altitude would be 12-15,000 feet. If, however, carbon dioxide tension is maintained -

i) the altitude level can be raised
ii) there is no confusion prior to unconsciousness.[204]

Normally in anoxia unconsciousness occurs when the haemoglobin percentage saturation of the jugular blood is 25% which almost corresponds to a dissociation curve with a tension of 19mm.Mercury.[133]

It is therefore reasonable to suppose that when any substance prevents oxygen from reaching the lung alveoli, anoxia will result, with the brain suffering more severely than any other body tissue.

In experimental exposures of dogs to concentrations of carbon monoxide causing unconsciousness and death within thirty minutes, circulatory changes were produced which were characterised/

characterised by dilatation, stasis, perivascular haemorrhages and oedema. There were diffuse degenerative changes throughout the brain.[222.] Dogs dying in 11-15 minutes showed considerably less damage while dogs kept in a state of unconsciousness and near death for several hours by exposure to gas, evinced much more extensive damage; and dogs surviving this exposure for periods of one hundred and sixty- five days supplied evidence that much of the damage to the brain was of a permanent nature.

Heyman[112.] and his associates also using dogs concluded that irreversible damage to the cortical cells occurs after five minutes of circulatory arrest. Developing this aspect on a larger scale, the period for which cortical cells could withstand deprivat-:ion of oxygen without undergoing irrevocable degenerative changes has been determined with reasonable accuracy by Gildea & Cobb[78.] who, as a result of experiments performed on cats, indicated that cortical cells cannot withstand cerebral anaemia for more than ten minutes and this was asserted to be a liberal estimate.

Certain observations indicate that the conclusions reached experimentally are equally true for the human brain. The cases of suicidal poisoning are, surely, analogous to the experiments producing anoxia in cats and dogs. The victim closes all windows and doors, puts his head in the gas/

gas oven, and is quickly rendered unconscious by the rapidly increasing concentration of coal gas. In effect the association of haemoglobin and carbon monoxide is so rapid, due to the rising concentrat-:ion, that the victim is asphyxiated. There is no question, in such a case, of toxic effects ~~of~~ from carbon monoxide or from other agents contained in coal gas but an immediate deprivation of oxygen from the brain.

Confirmation of this cerebral anoxia and its effects are reported by Steegmann[196] in an article called "Encephalopathy following N_2O Anaesthesia". The statement, purporting that death following anaesthesia induced with nitrous oxide might be the result of cerebral injury, was suggested by Caine.[35] This was confirmed in May and November of 1936 but Steegmann[196] followed up these reports with anatomic evidence suggesting that encephalopathy ensuing, was due to oxygen deprivation regardless of the anaesthetic used.

A typical case was shown at the post mortem of a young female who had died following anaesthesia. Degenerative changes in the cerebral cortex were seen which were more extensive than the macroscopic appearance suggested and showed considerable variation not only in the selectivity of the laminae involved but also in the different regions of the brain affected. In general, the most consistent and striking type of degeneration was found/

found in the laminae of the third and fourth layers. It was seen in the crown of the convolution and frequently became more extensive at the depth of the sulcus where all layers were involved. At the frontal pole, the degeneration was most pronounced in the third layer and in areas in the third and fifth layers. In the mid-frontal region, the third and fourth were most involved with occasionally lesser involvement of the fifth and sixth layers. Areas were seen in which only the second layer remained. In the central cortex, areas were present in which the intermediate layers and the sixth layer were most involved. In the parietal region, the third and part of the fourth layer were most involved, and in places the degeneration had selected the third and fourth layers. In the insular cortex involvement of the second and third layers, sometimes accompanied by degeneration of the fifth and sixth layers, was present. The degeneration of the occipital region was of the greatest severity, all the layers being involved in many convolutions. In places only the second layer was spared or the second layer and the layer of large ganglion cells were left intact. Even in this region, the third layer was seriously affected.

The degeneration consisted of areas of devastation, the tissue being in a spongy state and consisting of a network of fibroblasts, connective/

connective tissue, newly formed capillaries, and capillary sprouts. The tissue spaces were filled with detritus, droplets of fat and fat-filled compound granular phagocytes. The ganglion cells had almost completely disappeared; those present were in various stages of degeneration by shrinkage, swelling and dissolution or by what resembled the ischemic type of cellular disease. The pericellular spaces of the remaining ganglion cells were widely dilated. The large pyramidal cells of Betz showed calcification in some areas and in others were undergoing the anoxial reaction, probably as a result of the destruction of the white matter lying below; the re-action of the neuroglia was reduced in the areas of devastation, but large astrocytes were present above and below these areas. The microglial cells showed thickened and retracted processes. The areas of cortical destruction were accompanied by demyelinisation and the axis cylinders were interrupted and broken in their course through these zones. In the degenerated areas in the white matter there were both demyelinisation and destruction of the axis cylinders and a large number of compound granular phagocytes and protoplasmic astrocytes in the form of so-called gemastate cells were present in the same region. There was generalised venous hyperaemia especially in the areas of necrosis.

The changes in the neostriatum were identical

in/

in type with those in the areas of destruction in the cortex, viz., degeneration of caudate nucleus showing calcified ganglion cell, compound granular cell, and debris. Except for secondary degeneration of pyramidal tracts and other projection fibres, no pathological process of significance was observed in the brain stem or cerebellum.

Without it being assumed that individual types of change in the ganglion cells are in any way "specific", the changes above have been described experimentally, for the absence of arterial diseases and the strongly laminated character of the degeneration differ in no way from those associated with ordinary anaemic necrosis of the brain following occlusion of a cerebral artery.

Identical lesions, showing degeneration of the cortex and the basal ganglia, occur in other conditions which produce deprivation of oxygen in extensive areas of the brain, e.g. cases of delayed death after hanging; cases of strangulation; cases of ligation of the carotid artery.[61, 57, 26, 185, 161, 107] The shorter the time of survival after the anoxic stage, the more widespread is the distribution of the lesions, whereas a longer survival is followed by more discrete selection of the degenerative areas. The bulbar and vital centres suffer oxygen deprivation much longer than the cerebral cortex and basal ganglia but the latter are particularly vulnerable.

In a case of post-anaesthetic death due to cyclo-propane/

cyclo-propane, the neostriatum was not involved although the cerebral cortex showed similar degenerative changes as above, and the ganglion cells of the pallidum exhibited ischaemic changes. There were dark, basophilic globules in the tissues and calcification in the walls of some of the arteries. No significant changes were present in the thalamus, brain stem, nor cerebellum.

In the basal ganglia, degeneration of the neostriatum alone, occurred in two cases, one in ligation of the carotid artery reported by Muller, and in a case of delayed death by hanging.[61] In the former, the cerebral cortex showed a severe degenerative change with cellular defects, both diffuse and patchy distribution.

Döring states that the pallidum is usually, but not always, spared after ligation of the carotid artery. This may be because the pallidum receives part of its blood from the anterior choroidal artery which may receive a collateral blood supply from branches of the posterior cerebral or posterior communicating artery. It may be because the pallidum has, according to Putman, a richer capillary network. Nevertheless, degeneration of the pallidum with sparing of the striatum may occur. This was described in some of the cases reported by Courville.[47] Degeneration of both the striatum and pallidum was present in cases of post-anaesthetic encephalopathy reported by

Lowenberg/

Lowenberg, Waggone and Zbinden, in a case of ligation of the carotid artery (Döring) and in cases after hanging (Deutsch and Döring).[57, 58] The degeneration of these structures, associated with other conditions in which an anoxic or anoxaemic factor is present has been explained by A. Meyer.[154] The cells of the cerebral cortex exhibit not only a peculiar sensitivity to lack of oxygen but also a tendency to degeneration of certain layers; Meyer maintained that Sir William Gowers's "system factor" and Spielmeyer's "vascular factor" cannot be separated and he expressed the belief that phylogenetically the vascular supply of a region clearly follows its parenchymatous differentiation and adapts itself to the needs of the parenchyma.

The great variability in the site of cortical degeneration is dependent on the vascular factor. Any inherent resistance of the tissues in such cases apparently influences the site of degeneration only to a slight degree when the local blood supply fails.

In general it is true that the brunt of the degeneration and devastation falls on the intermediate cortical layers whether the oxygen deprivation be from anaesthesia, hanging or carotid ligation.[61] The white matter is less sensitive to anoxia than is the cortex, but it has a poorer blood supply and may, under certain circumstances, suffer more from anoxia. In an anaesthetic death from nitrous oxide anaesthesia the basal ganglia showed the same degeneration as did the/

the cortex. In the caudate nucleus and putamen there was loss of ganglion cells and the remaining tissues contained compound granular corpuscles, capillary sprouts, and cellular debris. The degeneration was patchy and, in the putamen was most pronounced in its supero-lateral aspect. The globus pallidus was degenerated to a lesser degree. The thalamus, basal ganglia and cerebral cortex were all well preserved except for mild chromatolysis of the nerve cells.

In deaths following poisoning from coal gas, lesions have been recorded in every part of the nervous system, mostly diffuse in nature. At an early stage the nerve cells show acute swelling and eventual chromatolysis. Some changes are ischaemic, others sclerotic; local softening or patches of bleaching may ensue and there may be acute swelling of oligodendroglia and of microglia. Degeneration of the parenchyma is more obvious with irregular necrosis and reaction on the part of microglia in the shape of macrophagic overgrowth.

The endothelium of the capillaries, precapillaries and small vessels, swells and may be shed with a tendency to occlusion from endarteritis. Perivascular and intra-mural infiltrates are frequently seen but these are not inflammatory so much as toxic or 'symptomatic'. Such lesions can develop locally or be spread more or less evenly over wide areas. Some specific types of incidence should be noted.

(1) /

(1) Cortex

A peculiar involvement of third and fourth cortical layers has been remarked by Fuelchan as far back as 1888 and cases appeared sporadically in the literature in 1914, 1925 and 1926.

They are the seat of continuous unbroken softening throughout both hemispheres; zones packed with fatty debris amongst which are neurone structures in every stage of decay, though a few put up a resistance.

Limited with some sharpness in both outer and inner side it contracts, with the relative integrity of the remaining cortex where, however, satellite microglia are grouped round the ganglion cells. Overgrowth of microglia and of blood vessels is already a feature of the necrotic band where death occurred in 24-27 days. Failure to find it usually means that death occurred in a few hours or days, liquefaction not having had time to begin.

(2) Basal Ganglia

A predilection for the inner part of the globus pallidus or for that nucleus as a whole has long been noticed; twelve samples were collected.[125, 116, 92.] The degree and severity of their involvement varied with the degree and duration of the poisoning and with the subject's age. All grades from slight perivascular dissolution to complete tissue necrosis with surrounding glial reaction and numerous macrophages may be found.

The putamen, too, is sometimes concerned and

more/

more rarely the optic thalamus, the hypothalamus, substantia nigra and internal capsule.[215,6] Apart from softening, moderate or intense fatty degeneration may occur in the striatal parenchyma, with productive glial reaction but also with some glial involution while analagous processes affect the smaller blood vessels of the region.

Lesions are seen now and again in the sub-:cortical white matter in the mid brain, pons, medulla oblongata, cerebellum and cord (mostly cervical): spinal and cranial nerve roots may likewise be damaged. Zipf describes paraplegia at the upper lumbar segment.

In general terms the syndrome comprises:

(1) Widespread toxic degeneration of the neural parenchyma.

(2) A mesodermal reaction in the form of glial hyperplasia and involution.

(3) A hyaline, calcareous fatty change in vascular coats, with effusions, thrombosis diapedesis of red blood cells owing to disease of vessel lining.

(4) Perivascular and intramural collections of round cells etc. The ecto-mesodermic barrier is injured.

Experimental pathology confirms this general description[212,114] although there is no doubt that animals may react differently.

These findings are in keeping with those of Yant and his collaborators[222] who asphyxiated dogs rapidly by gas. From these experiments it was clear that carbon monoxide from the gas caused asphyxia of brain/

brain capillaries, changes in the endothelial walls marked by dilation, leaking of fluid and consequent perivascular oedema. If injury is great enough, haemorrhage will result. The readily produced lesions of globus pallidus in the dog, for example, can in no way be reproduced in rodents such as the rabbit and guinea pig. With reference to this it is interesting to note that in the lower animals e.g. rodents where the globus pallidus contains no iron there is no softening of that organ when exposed to coal gas or cyanide.

From the above listed pathological findings it is evident that symptoms affecting the victims of acute gas poisoning could take place purely from the replacement of air by coal gas i.e. anoxia, and the people so affected would suffer predominantly in psyche as opposed to soma. The chief cells subject to anoxic changes are obliterated i.e. in the cerebral cortex and third and fourth layers[34,44] - in fact in no way different from other causes of severe cerebral anoxia as cited above.[156] Without doubt the basal ganglia are affected in every case of gas poisoning but not so, however, in every case of anoxia.

Selective lesions of the brain have been studied for many years in order to determine the "why's and wherefore's" of vulnerability. It is recognised pathologically that general paresis has a tendency/

tendency to affect the anterior two-thirds of the cerebral cortex and the striate body leaving other parts of the basal ganglia intact. The posterior parts of the cortex are affected most markedly in 'senile dementia'; the occipital lobe is picked out in Shilder's disease and the frontal pole and temporal lobes with the 'ancient hippocampus' are left intact in Pick's disease; the cornu ammonis and the Purkinje cell layer are affected after epileptic convulsions and the substantia nigra in epidemic encephalitis; the striatal lesions in Kinnier Wilson's disease, and the anterior part of the globus pallidus in Kernicterus and gas poisoning.

The latter was first described by E. Klebs[123.] in 1865 and later confirmed by Poelchen,[172.] Dana,[46.] Grinker,[93.] etc.

Besides the selectivity of the globus pallidus shown in coal gas poisoning, other conditions such as deaths occurring following anaesthetics, cyanide and manganese poisoning, carbon dioxide and barbiturate poisoning show this selectivity, too.[56.] In all of these conditions the globus pallidus may show identical changes but with much less regularity.[33.]

The common basis of the lesions produced by these various agents is said to be 'anoxia' due to either;

(1) Asphyxia.

(2) Respiratory failure.

(3) Destruction or obstruction of haemoglobin.

(4) Vasomotor changes.

The/

The term "pathoclisis" was coined by C. & O. Vogt in 1922 meaning, in fact, the "pathological state which leads to selective vulnerability". They averred that differences in architectonic structure point to differences in what he called "physico-chemisimus" - these making unequal inclination to disease. In 1925 Spielmeyer recommended the investigation of the vascular system as a more concrete approach to selectivity.

We know that the vascular supply of a region closely follows its parenchymatous differentiation - adapting itself for its formation.[169]

It is relevant at this stage to consider in detail the vascular supply of the basal ganglia.

The striatum (putamen and caudate nucleus) with the exception of the postero-ventral recurved part of the tail of the caudate nucleus and of the adjoining part of the ventral crest of the putamen receives its blood supply from the striate arteries (striato-capsular arterioles).

In two-thirds of the cases, those for the antero-medial ventral tip of the head of the caudate nucleus and of the putamen are derived from the anterior cerebral artery; those for the remaining portion of the caudate nucleus and the putamen are from the middle cerebral artery. In one-third of the cases, all striate arterioles are derived from the middle cerebral. The postero-ventral recurved part of the tail of the caudate

nucleus and the adjoining post-ventral crest of the putamen are usually supplied by the anterior choroidal artery.

The medial and intermediate segments of the globus pallidus receive their blood supply from the arteria-choroidea anterior (pallido-hippocampo capsular artery) except in those rare occasions in which this artery is vestigial.

The lateral segment of the globus pallidus, with the sole exception of its ventral tip, receives its blood supply from the anterior choroidal artery in twenty-five per cent of cases; from the striate arterioles of the middle cerebral artery in one quarter cases and its lateral part of the striate arterioles from the middle cerebral artery in fifty per cent of cases and its medial part from the arteria choroidea anterior.

The antero-lateral tip of the lateral segment of the globus pallidus is supplied from the striate arterioles of the anterior cerebral artery in about two-thirds of the cases, from those of the middle cerebral in one-third of the cases; furthermore, there is always a sharp cleavage between the arterio-capillary bed supplied from the striate arterioles and that supplied from the anterior choroidal artery.

The undivided length (i.e. the length measured from the last source of the abundant blood supply or from the last reasonable anastomosis to the terminal district/

district) of the anterior choroidal artery is greater than that of any other cerebral artery of similar calibre; all other conditions being equal, the circumstance tends to predispose this artery to thrombosis under any conditions or circulatory disturbances favouring clotting. I did not find any alteration in the clotting time in coal gas poisoning. This is discussed more fully in Chapter Vlll.

It is also seen that the anterior choroidal artery supplies the two most vulnerable structures of the human brain - the globus pallidus and cornu ammonis, the former by its most anteriorly recurved terminal branches, the latter by its most postero-ventral branches; along with the fact that there is great paucity of significant supracapillary anastomosis in the striatum and pallidum and its capillary bed (pallidum) is less dense than that of any part of the cerebral cortex; finally these pallidal vessels have also been shown to be devoid of vasa vasorum.

Autopsy examination shows that in gas poisoning thrombosis of the recurving pallidal branches of the arteria choroidea anterior is a common finding. The lesions begin and are most severe within the anterior part of the terminal district supplied by the artery. Accordingly the small dorsal adjacent strip of the internal capsule (also supplied by the same branches of the anterior choroid artery) is likewise involved/

involved and the small postero-lateral-ventral part of the globus pallidus usually not supplied from the arteria choroidea anterior is usually spared; its many peculiarities noted above - recurving course, great length, paucity of blood supply and small calibre, so favour the occurrence of thrombosis that it may be the only artery affected.[3]

In addition to this single arterial thrombosis, there may be additional thrombosis of the long thin venules in the cerebral white matter (which are the most susceptible of the intra cerebral veins to thrombose) and of venules at the medial margin of the putamen, where venous circulation may be injured due to the swelling of the softened adjacent globus pallidus. It is not therefore surprising to find that such diverse maladies as gas poisoning, nitrous oxide anaesthesia,[44] cyanide[73,119] and barbiturate,[52,87,4] manganese[40] and carbon disulphide poisoning,[7] as previously mentioned, may produce a similar pathology in the extra pyramidal nuclei, by virtue of their asphyxiating qualities.

Although all the above facts are indisputable, all these noxious substances produce softening of the globus pallidus with much less regularity than with coal gas. Similarly there is a wide difference between the constant findings in coal gas poisoning, and the apparently casual lesions of this region in severe anaemia. It is relevant here to bring experimental evidence to light in relation to coal gas/

gas poisoning.[156]

The globus pallidus in rodents such as guinea pigs and mice is not selectively involved whereas in dogs a similar lesion to that found in man is produced. It is significant to note that in the dog the anterior choroidal artery has not the long and tortuous course and mechanical peculiarity as described in man in the preceding pages. This would make anoxaemia and thrombosis less likely in the dog and yet the globus pallidus still preserves its susceptibility.[152]

Cerebral tissue is, thus, seen to have a low threshold to anoxia. Irrespective of the underlying etiology of this anoxia, the most constant pathological change is degeneration of the intermediate cortical layers with a varying involvement of the extra-pyramidal nuclei. At autopsy, following death from coal gas poisoning, a similar pathology is found in the cortex but the basal ganglia are constantly affected.

This selectivity of the basal ganglia can be partly explained by the paucity of their blood supply, but the constancy of their involvement indicates the existence of some other factor.

Plate lV.

Scottish Daily Mail

PRINTED AND PUBLISHED IN SCOTLAND — THURSDAY, OCTOBER 12, 1950

TO MacA.

Gas leak kills family of three in home

Experts hunt for leak

By Daily Mail Reporter

GAS experts were early today hunting for a leak which killed a 56-year-old Glasgow couple and their 12-year-old adopted son in their West Street, Kingston, tenement home.

The man, William Barker, unemployed labourer, his wife, Alice, and the boy Billie were found dead in their ground-floor kitchen of their ground-floor flat last night.

An ambulance attended the tenement at which the resident this morning gas was still escaping into the street.

Police said last night that the family had been dead for at least eight hours when they were found. William Barker and his wife were lying across Billie, who lay on a bed near by on a couch was Billie.

The experts think the gas may have started from a leak in the main near the flat through the floorboards.

The dead family were discovered by James Black (24), of Hamilton Street.

He was passing the tenement when he smelled gas coming from the ground windows of the Barker flat.

He tried unsuccessfully to open the window, then borrowed a key from a neighbour and with a handkerchief over his mouth entered the smoke-filled kitchen.

Black told me: "I saw the couple lying on the bed with a blanket over them. Then I found the boy.

Few visitors

Eighteen-year-old Celia Christie, of Mackrow Street, who on her way home from work with her friend Jessica Gilfoyle, where she met Black trying to climb in the window. She also entered the flat and helped Black.

Detectives from the Southern Division last night examined the flat, which was later sealed up.

Neighbours had not seen the Barker family since Tuesday night.

They said the Barkers were never seen inside who had been out of work for some time, but made a little money from odd jobs.

Mrs. Fullerton, who lives upstairs, said: "I smelt gas earlier in the day, but thought nothing of it. I hadn't seen the Barkers for some two days. It is true very much to themselves."

Eleven-year-old Jimmy Gilfoyle, who lives next door and was playmate of Billie Barker, said he had seen him alive in the tenement on Tuesday night.

"Billie was in the same class as me. He had been off school for some time—he broke his leg at a match," said Jimmy.

The Barkers had been in the house for 18 years.

Mrs. Ann Gilfoyle, who is in one of the tenement flats, Barker's next door, said: "I left for work this morning and did not smell gas. It is

ACCIDENTAL GAS POISONING.

REVIEW OF CASES UNDER INQUIRY.

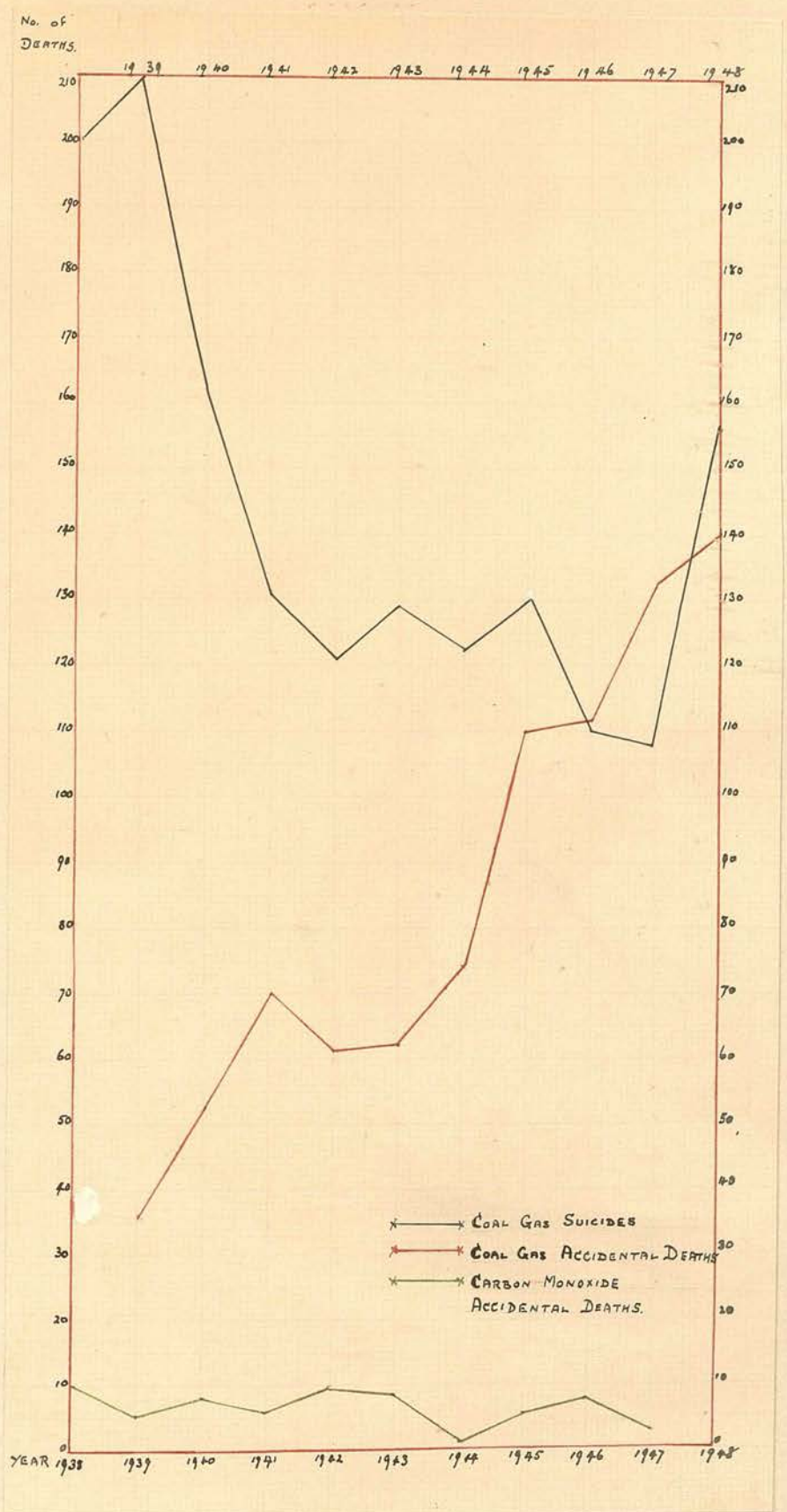
The total number of cases abstracted from the records of those suffering from gas poisoning and admitted to the Royal Infirmary of Edinburgh from the month of April, 1938 to the month of March, 1948 numbered 271. Of this total 234 cases were classified as attempted suicides, 23 of which were successful. The remaining 37 cases were accidental coal gas poisoning, 5 of whom died while in hospital.

If there was any doubt as to which group a patient belonged, I interviewed either the patient or a relative and established the true state of poisoning. Thus, the figures quoted for the accidents and suicides have been corrected within the limits of human error.

From this series of cases, it is clearly seen that there is little seasonable variation and the year by year admission rate shows no gross alteration, which is contrary to the generally held opinion. There was, however, a distinct fall in the admission rate during the years 1941-1945 which appeared to be due to the remarkably low suicide rate from coal gas poisoning during these years. Such small groups of figures prove little statistically but this difference in admission rate during the war years ran parallel to the Registrar-General's overall figures for Scotland. Whether this decrease was due to the varying fortunes of war, the greater bondship between people, leading to lessening of depressive

phases/

Table 3.



DEATHS FROM GAS POISONING.
1938-1948 Scotland.

phases, the call up of the potential suicides, or extroversion of interests, is purely speculative. (Table 4).

During this decade, the most striking and alarming feature, is the rapidly increasing accidental death rate over all Scottish Regions from coal gas poisoning. Deaths due to inhalation of car engine exhausts provide a small but constant number of cases each year. The causes of accidental poisoning by coal gas can be divided into two groups:-

(a) Faults in the appliances, or pipes leading to them.

(b) Carelessness of the user.

Out of 518 cases of gas poisoning reported in Ohio in 1936, 288 of them were due to defective household appliances. This factor, I feel, is in evidence in this country as well, for, during the war, pipes and couplings were neglected and unauthorised persons replaced supply pipes and extensions. There can be little blame attached to war damage in Scotland. Another source of danger lies in the varying of gas pressures, (owing to the shortage of supply during recent years) - so low in some cases that the flame has been extinguished and with subsequent raising of pressure the non-lighted gas has issued freely into the room. A similar state of affairs may arise with the use of the shilling meter.

Although the number of consumers has increased by two thousand since the war, the gradual but steady increase/

increase in accidents cannot be wholly due to "user carelessness" and the conclusion is that the source of gas is faulty.

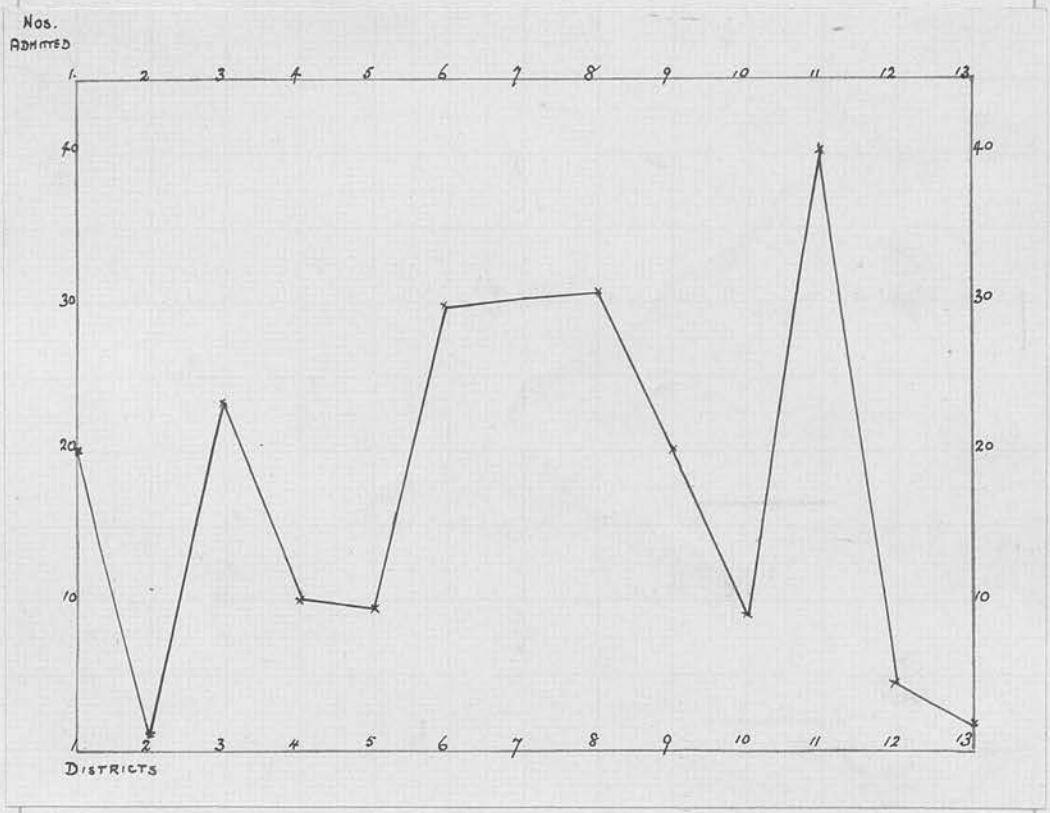
> Mr. J.G. and Mrs. J.G. aet 76 and 77 were found in their homes having inhaled coal gas which was leaking slowly from a jet into the room. They were admitted unconscious to hospital and died within thirty-six hours.

> R.L. aet 10. a young boy in the habit of reading in bed, put his book away and went to sleep, as the gas supply was failing and the light becoming dim. His sister, entering the house half an hour later and finding the gas finished, put one shilling in the meter and lit the kitchen gases. The boy was found one hour later in coma; a stream of coal gas was issuing from the open unlit jet in his room.

It is relevant here, to point out that the characteristic smell of coal gas, due to impurities of sulphur and hydrocarbons, is insufficient as a warning signal because the olfactory organs become rapidly insensitive to the odour. The cases mentioned briefly above would never have occurred had the odour of the slowly escaping gas been more pungent. McNally, following methyl chloride refrigerator poisoning, used acrolein as a pungent indicator.[142] It could well be added to coal gas as it is ill-smelling and irritating to both nose and eyes and therefore would give timely warning of a leak.

Table 3 is sufficient in my mind to warrant enquiry by both Health and Fuel and Power Ministries to ensure efficient inspection, supervision and control/

Table 4.



Cases admitted - 1938-1948
showing District of Edinburgh to which
patient belonged.

control of household fixtures, abolition of badly designed stoves, flexible tubing, shilling meters etc., and in the field of prevention, the public should be educated in the daily hazards of coal gas.

Sex Incidence

There is no outstanding difference as regards sex in the 233 cases of suicide, the average per month working on the ratio of 50:50

Age Incidence

The majority of suicidal coal gas cases fall into the age group of 45-65. This is in keeping with the years of strain and stress and with a decreased resilience to life's physical and mental burdens, illustrated by the following two cases.

> Mrs. A.B. aet 63, a diabetic living alone was subject to fits of depression. Her son died suddenly and following this tragedy she attempted to take her life by gassing.
>
> Mr. E.L. aet 60, following his wife's death attempted suicide by inhaling coal gas. He was found unconscious and revived with treatment.

DISTRICT

A table was compiled of all cases admitted in their respective postal districts, in Edinburgh; From Table 4 the peak incidence is seen to occur in E.11. This is a most densely populated area in comparison to E.2, 10 or 13.

(a) The majority of the houses are supplied with gas for heating and lighting.

(b) It is a district occupied by the 'lower level income/

Plate V.

PRIVATE & CONFIDENTIAL. GAS ACCIDENTS.

If, unfortunately, the person to whom this is addressed is no longer living, a relation will help this inquiry by kindly answering, so far as possible, the questions asked. The date of death and the cause should be mentioned.

.....

It is clearly understood that all information is strictly confidential.

By answering these questions you will assist us in completing the Hospital records.

1. (a) Were you in good health up to the time of your admission to Ward 3 ? .....

.....

(b) Did you have any illness 3-4 weeks after your discharge ? .....

.....

(c) If so, how did the illness start ? .....

.....

(d) What was the type of illness ? .....

.....

(e) Did you recover completely ? .....

.....

2. Since you were a patient in Ward 3, Royal Infirmary, Edinburgh, have you been in good health ? .....

3. HAVE YOU HAD ANY TROUBLE WITH YOUR

(a) Ears ..... (b) Eyesight .....

(c) Speech ..... (d) Arms or legs .....

(e) Shakiness of arms and legs .....

(f) Chest ..... (g) Headaches .....

4. MEMORY.

(a) Has it remained normal always ? .....

(b) Do you fully remember your accident ? .....

.....

(c) If not, has it returned now ? .....

(d) Do you think it got worse after the accident and has never been good since ? .....

.....

5. Do you think you have altered in any way since the accident ?

.....

If not, do other people think you have altered in any way ?

.....

QUESTIONNAIRE.

income groups', and

(c) is in consequence housing people with a lower standard of education amongst whom are found the majority of psychotics: ergo, a greater suicide rate.

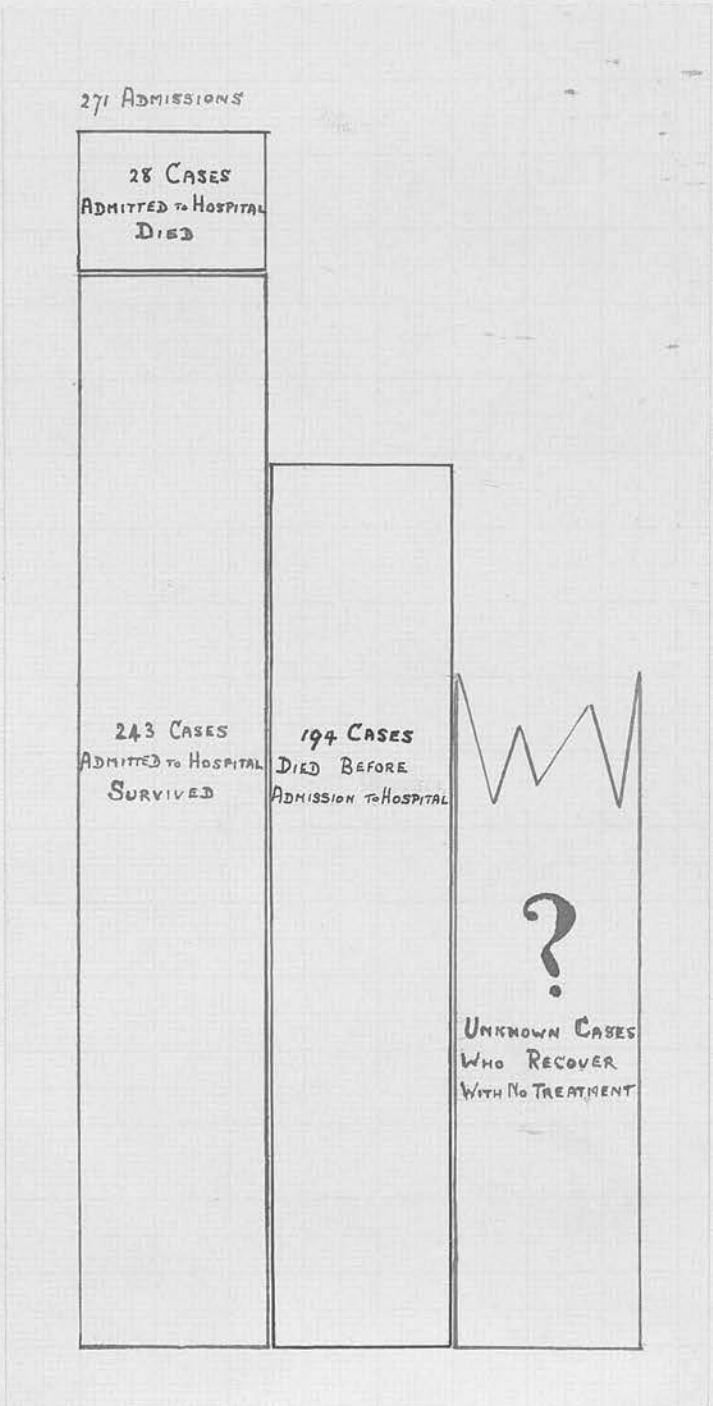
As those who live in the overpopulated districts are removed to new housing areas with equipped electricity and modern gas appliances, new and more sophisticated methods of suicide may emerge; already the admission rate for barbiturate suicidal poisoning is rising yearly. A similar comparative survey in 5-10 years time will reflect in some measure the success of slum clearance and the raising of the general educational level.

INQUIRY

In order to inquire closely into the health of the remaining 211 who had unsuccessfully attempted suicide and the 32 accident cases who recovered, a questionnaire was compiled.

Owing to the poor intelligence of the majority of the patients under surveillance it was essential to frame this questionnaire directly and simply (Plate V). Even so, results might be expected to be poor for many of these patients were unemployed and constituted the 'gypsy group' of the population. The final question at sight seems useless. Its worth was established however in the replies received especially with regard to minor degrees of alteration of a mental nature which has occurred. As shown in Table 6 , of 243 questionnaires sent out there were 163 replies. 80 were without answer. Out of these

Table 5.



Survey of Cases of
Gas Poisoning.

163 replies, 73 were interviewed personally as they had complained of some untoward symptom, either affecting their physical or mental state since the incident of gassing.

The evaluation of degrees of mental damage following poisoning is often difficult, for it is evident that the largest number poisoned will be suicidal in origin and they already are suffering from pre-existing psychoses; where this was the case the patient was admitted to a state or private Mental Institution and the psychiatrist in charge was interviewed. In no case in the following discussion was the psychiatrist of the opinion that the gas poisoning had increased the pre-existing psychoses to any measurable extent.

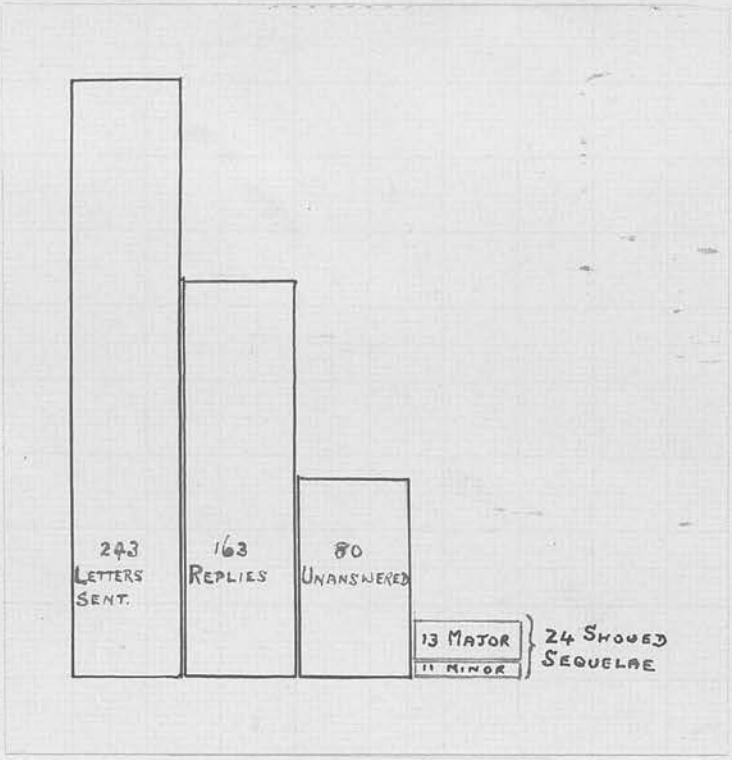
On page 56 it was seen that sequelae may arise from suicidal or accidental coal gas poisoning and of these two types from many other series it is evident that chronic poisoning can, without accompanying unconsciousness, produce severe after effects. Of 271 cases reviewed 13 developed major and 11 minor sequalae, a total of 24 cases. These figures become significant when we assess the number of people affected throughout Scotland by coal gas.

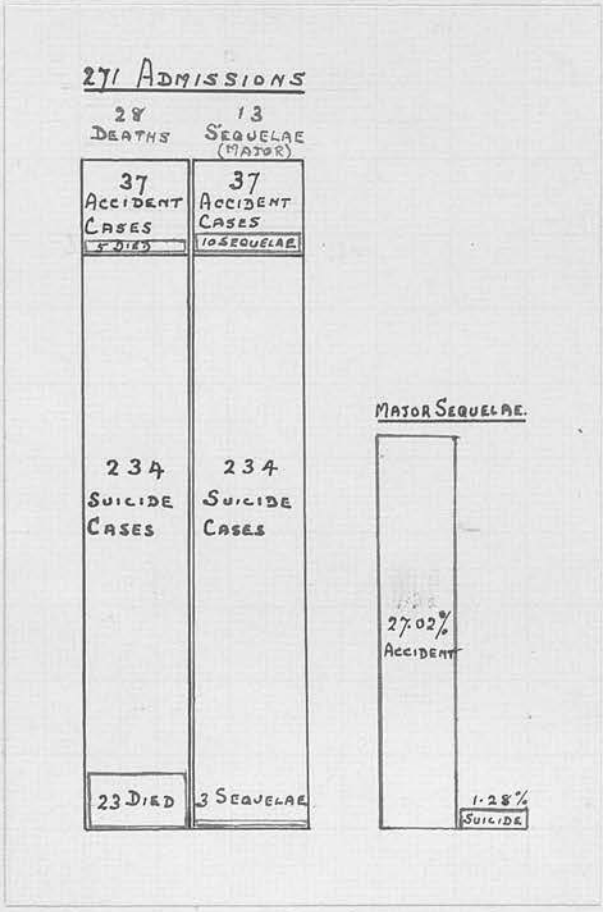
The Table V on the opposite page represents graphically three major groups:

(1) The number of people who were admitted to hospital suffering from gas poisoning in the 10 year period under review, showing the proportion who died.

(2) The number of people who died from gas poisoning/

Table 6.





Analysis of Survey.

poisoning in the same period in the greater Edinburgh area without being admitted to hospital.

(3) The broken column representing the part of the population which was gassed -
(a) over a number of years -
the garage hands,
fitter engineers,
Corporation gas workers etc.

(b) the suicidal 'failures' who were discovered by their relatives, revived in their homes, and in consequence never notified the doctor and hospital.

This latter column, therefore, represents an unknown number. From its ranks emerge sequelae with the central nervous system predominantly affected similar to the cases under review. The Americans have been concerned with this problem as the following clearly shows:-

During the Winter 1948-49, 32 persons with gas poisoning were admitted to the Neuromedical Service of the Los Angeles County Hospital. A number of the patients gave a history of symptoms indicating previous exposures. In none of them had a correct diagnosis been made prior to the acute, severe, and more obvious anoxial episode that led to their admission. The initial diagnosis made in the home, emergency wardroom or ward before a history could be obtained was often incorrect, even in the cases of acute anoxia. Amongst the initial erroneous diagnoses were schizophrenia, hysteria, syncope, food poisoning, epilepsy and expanding intracranial lesions. It seems likely therefore that many cases of acute and chronic anoxia due to inhalation of/

of coal gas go unrecognised.

> The typical case was that of Mr. C.H. aet 43, who, owing to the fact that he had embezzled a considerable sum of money and had been discovered, put his head in the gas oven and was found two hours later by his wife. She realised the motive for his attempted suicide and did not inform her doctor or the police. He made a spontaneous recovery over the next 4-5 days. The case only came to my notice as the patient developed marked neurological sequelae; these sequelae would have been completely misinterpreted if the wife had not broken down and told her doctor the full facts of the case.

The second case represents that unknown group who are subjected to small amounts of coal gas over many months or years.

> Mr. J.H. aet 49, had worked for many years as an engineer concerned with the connecting of main gas pipes. On several occasions he remembered feeling breathless and dizzy, but after a few minutes in the fresh air he recovered and returned to his job; but for the very fact that I was interested and on the look out for such cases the etiology of his basal ganglion lesion would have been misinterpreted.

From this broad classification it can be seen that sequelae developing from patients in Group 1 can be obtained from the questionnaire, but figures for the unknown suicides and the important group of accidental gassing will remain forever unknown. These patients may constitute the minor malady group, the headaches and psychoses so often labelled as neuroses.

Recovery Rate

The majority of patients were comatose on discovery/

discovery. It is striking that out of 271 admissions only 28 deaths were recorded. Of these, 5 resulted from accidental gassing and the remainder were suicidal showing that the majority of people who succumb, are the ones who have concealed their intentions, and are found dead in the first instance, by virtue of their secrecy.

Method of Interview for Assessment of Recovery:

All patients giving positive indication that they had developed symptoms following their gassing attack, were interviewed. When these results were examined, it was evident that two types of sequelae were forthcoming and, for lack of classical terminology were designated (i) Major, and (ii) Minor. Of 234 cases of attempted suicide by coal gas, 3 showed 'major sequelae' of varying kinds, whereas of 37 cases of accidental poisoning by coal gas 10 cases showed major sequelae and 11 cases showed minor sequelae. Accidental poisoning, from this small but not insignificant group, shows a much larger proportion of patients suffering from 'after affects'. There is no evidence or comment on this fact in the literature. Patients who had been permanently affected by coal gas were found in 27.02% of accidental cases but in only 1.28% of attempted suicide. This would tend to bear out the statement of Lewis et al that "the concentration of carbon monoxide in the inspired air and duration of exposure have a profound effect

on/

on the ultimate results".[132]

The different methods of gassing is evident from 2 typical case histories.

> Mrs. H. aet 59, was found in a small room with door and windows tightly closed, the gas ring turned full on. The rise in the concentration of illuminating gas in such circumstances will cause asphyxia as surely as drowning, for the haemoglobin rapidly combines with carbon monoxide contained in coal gas displacing all oxygen. Death is due to anoxia.
>
> Mrs. P.G. aet 62, was found lying on her bed in an unconscious state. A slow leak had percolated from a fractured main pipe in the street into her cellar and slowly diffused through the house taking 6-7 hours to allow a high enough concentration to make Mrs. P.G. lie down feeling sick. The poisoning was slow and over a considerable period.

The question now arises, does the patient who loses consciousness due to asphyxia (a pure anoxia) suffer in any other way from illuminating gas? The greatest percentage of major sequelae was found in the slowly poisoned group; if anoxia was the causal factor in both groups then the discrepancy shown in sequelae of suicide and accidental cases should not arise.

DIAGNOSIS.

Full and comprehensive descriptions of physical signs and symptoms of patients suffering from the various stages of coal gas poisoning[69] have been recorded, from the gas engineer who suffers from dyspnoea and faintness while working in a man-hole, to the florid and comatose suicide case breathing stertorously with coal-gas-laden breath, absent reflexes and an extensor plantar response.

I believe that such clinical findings are insufficient evidence and that to sustain a definite diagnosis in order that complicating factors may be excluded, it is necessary to assess the percentage of carbon monoxide in the patient's blood. Should a man become overwhelmed by coal gas either in the course of his work or while attempting suicide he may fall, striking his head, thus introducing the possibility of an intra-cranial injury which if untreated may cause death despite vigorous treatment of the gas poisoning.

> Case of Mr. R.B. aet 68, a plumber, climbed a ladder into a gas filled room and prepared to search for a leak of gas; he was overcome by the fumes and fell to the floor cutting his left temple. On admission his carboxy-haemoglobin was 25% and he was unconscious. By experience we know that this man should recover in 1½ to 2 hours. He failed to respond to inhalation of carbon dioxide, oxygen mixture; the laceration of his temple and clinical condition led to the belief that he was suffering from intra-cranial haemorrhage. A surgical opinion was obtained but no operative treatment could be undertaken owing to the rapid deterioration in his condition.

Post/

Post Mortem

General appearance; the body was that of an elderly, well nourished male showing post mortem lividity of the dependent parts and complete rigor mortis. There was no other external evidence of injury apart from the reddish discolouration surrounding the left eye.

Scalp.

Situated over the left temporal region was a small superficial scalp wound closed by 2 silk worm gut sutures. The temporal muscle over an area of 3-4 cms. showed evidence of contusion and bruising.

Skull.

Underlying the contused temporal muscle, there was a small linear fracture, 3 cms. in length, in the squamous temporal bone. The dura showed no abnormality.

Brain.

This showed external evidence of recent injury and was sent to the Neuro-Pathology Department.
They reported as follows:-

Microscopically a lesion is seen in the right orbital and temporal surfaces, typical of recently produced contusion. The foci of necrosis and haemorrhage are almost entirely confined to the cortex with only minimal involvement of the immediately subjacent white matter.

The post mortem showed a moderate number of small recent perivascular haemorrhages.

A diagnosis was made of cerebral contusions with small pontine haemorrhages.

A similar complication in diagnosis may arise when an attempt at suicide by gassing is preceded by an overdose of drugs. Frequently, this is done, not only to allay fear, but to diminish the nauseous smell of coal gas. If the carboxy-haemoglobin figure is not in keeping with the patient's clinical condition some secondary cause must be searched for.

Two/

Two cases come to mind and the urgent necessity for correct diagnosis and early treatment of all contributing factors commenced is convincing:

> Mrs. M.L. a young married woman left with a baby and deserted by her husband, took 22 tablets of 'Soneryl' and proceeded to gas herself.
> She was admitted in coma but a carboxy-haemoglobin estimation was found to be only 10% which was quite out of keeping with her present clinical condition, although she reeked of coal gas. A second factor was introduced when relatives found the empty phial of Soneryl tablets. She was treated as a barbiturate poisoning case and made a successful recovery.
>
> Mr. A.E., an elderly man with a previous history of an attempted suicide by gas poisoning. He was repelled by the smell of gas and before attempting to gas himself again he took 75 grains of aspirin. This added little to his comfort but constituted a complicating factor to his doctor. His carboxy-haemoglobin was less than 6%. He was treated on orthodox lines and made a complete recovery.

The early symptoms of gas poisoning may simulate alcoholism and apart from the fact that no active help is given to the victim, there is the consequence of police detention. The most necessary adjunct for the expert witness in such a case is the carboxy-haemoglobin percentage. Not only in such medico-legal cases is it necessary but also in murder with arson, and in compensation cases. Direct proof of the presence of carbon monoxide in the patient's blood whether he be alive or dead must be obtained to make an undisputed diagnosis.[85]

> Mr. F., a workman in a gas producing plant was reported to have fallen asleep/

asleep during the night shift close to a gas retort. He was discovered by his mates who were unable to rouse him and he was admitted to a general hospital ward in coma. During the next 48 hours he recovered slowly with abnormal behaviour and he developed a transient blindness. He was diagnosed as a case of hysteria or G.P.I. His cerebro-spinal fluid report showed a positive Wassermann although the blood Wassermann and Kahn were both negative. This gave some credence to the fact that he might have a specific lesion. Further serological tests proved negative. Within the next few weeks he made a full recovery and his vision was within normal limits.

It is my firm belief that the above Mr. F. was overcome by leaking gas and suffered transitory mental changes as a result. This case is a striking example of the necessity of estimating the carboxy-haemoglobin percentage from a diagnostic point of view and for compensation claims made by Mr. F. either relating to his present state of health or to future sequelae which might be of a permanent nature.

Mr. J.C., a miner, aged 60, who had been well all his days, collapsed suddenly with severe pain in his chest while in a side shaft attending to a petrol engine. He was treated in hospital as a coronary thrombosis. Several days later he developed emboli and as a consequence of one lodging in his middle cerebral artery he became hemiplegic.

Close questioning of this man and of his colleagues revealed the fact that, because of this engine the air in the side shaft was so 'fouled' by exhaust gas that no lamp would stay alight. The local firemen had full knowledge of this but had failed to report it in their logbooks. It is significant that following the admission of Mr.J.C. to hospital the management installed a ventilating system/

system. This man receives no compensation as the hospital records gave no hint that his condition might be wholly or partly due to noxious gases.

It is evident that in any hospital undertaking the treatment of gassed victims, a table must first be drawn up of signs and symptoms which are found on an average and correlated to an approximate carboxy-haemoglobin level in the blood. Standards obtained by other units do not suffice although the same laboratory technique is used, for different technicians, especially in colorimetry differ as much as 10-15%.

The test used in all cases in this series was that of Sayers and Yant being, in fact, a colour comparative test; U.S. Army Lab. Methods (1948).

Reagents — Table 7a.

2% Pyrogallic acid (fresh)
2% Tannic acid.
Equal parts of each.

Standard

Add 10ccs. of normal blood to 0.5 gm. pot. citrate, divide into two portions and dilute one portion 1:10 with distilled water. Saturate the other by bubbling coal gas through it and then dilute 1:10 with distilled water. From these, mixtures 0-100% in steps of 10, each mixture making 1cc. in volume. To each add 1cc of the above reagent and seal immediately by pouring melted paraffin wax over the contents. Seal with cardboard and wax when dry. A fresh standard should be prepared weekly as fading occurs.

Method

Place 1-2 ccs. of fresh blood in a test tube containing a knife point of pot. citrate. Cover with liquid paraffin. Lake 0.1cc. of this blood in 0.9 cc. distilled water adding 1cc. of the reagent. Allow to stand for 15 minutes and compare with standard solutions/

Table 7 (a).

PERCENTAGE SATURATION OF THE BLOOD WITH CARBON MONOXIDE AND CORRESPONDING PHYSIOLOGICAL EFFECTS.

Per Cent. of Haemoglobin in combination with carbon monoxide.	Physiological Effect.
10	No appreciable effect except shortness of breath on vigorous muscular exertion.
20	No appreciable effect in most cases except short wind even on moderate exertion; slight headac in some cases.
30	Decided headache; irritable; eas fatigued; judgement disturbed.
40-50	Headache; confusion; collapse an fainting on exertion.
60-70	Unconsciousness; respiratory fail and death if exposure is long continued.
80	Rapidly fatal.
Over 80	Immediately fatal.

(McNally [141.])

Table 7 (c).

Per cent. of Haemoglobin in combination with carbon monoxide.	Physiological Effect.
5-10	No appreciable effect even on exertion.
10-20	No effect, slight breathlessness on moderate exercise.
20-30	Conscious, quite rational though anxious; some a little dazed.
30-40	Conscious but shocked; cold; confused.
40-50	Unconscious and collapsed.
50-60	Unconscious; death; seldom recoverable.

solutions as prepared above.
It is not advisable to use potassium oxalate as an anticoagulant as it causes an appreciable change of carbon monoxide to carbon dioxide on standing.

The table used by McNally[141] is reproduced as Table 7a. His estimation of the carboxy-haemoglobin was carried out by the use of Pyrogallic-tannic acid method (Table 7b). The figures shown in Table 7c, using an identical technique, produce comparative results in the lower concentrations. The most marked difference occurs above the 50% carboxy-haemoglobin level. The lowest concentration of carbon monoxide detected in the blood is .03%. In the alveolar air carbon monoxide has been recorded in concentrations as low as 0.00015% with the subject breathing 100% oxygen. It is thought that the body itself produces carbon monoxide, probably during the breakdown of effete red blood corpuscles.[191] Slightly higher concentrations are yielded, if the person has been smoking cigarettes, 0.01% to 0.27% and up to 5% in chain smokers with inhalations over a two-hour period.

The lowest concentration of carbon monoxide in the blood, known to produce untoward symptoms, is between 7 and 10%.[67] Workmen, usually those belonging to gas-main repair squads, who have been admitted with dizziness and breathlessness, are entirely symptom-free and able to do their work with concentrations of less than 7%. Whether or not this should be allowed must be considered when it is realised that it is in the slowly poisoned group that the major sequelae develop/

develop. Apart from this fact, the gas each day may not be eliminated completely from the blood so that there may be a build up to a significant concentration, towards the end of each week.

The critical level is considered to be a carboxy-haemoglobin of 50%. Patients having a concentration of over 50% on admission rarely survive. This figure is a delayed estimation of the concentration for the patient has been removed to hospital which often entails a considerable journey and carbon dioxide and oxygen are given as an emergency measure en route. The maximum percentage is therefore unavailable. It has been shown that age and anaemia increase the risk proportionately. Thus, in the aged, we find that faulty metabolism and deficient nourishment of the tissues with changes in the blood vessel wall, predispose them in a marked degree causing greater susceptibility.[82.]

The final point is one of importance especially where teaching hospitals are concerned for the cherry-pink colour described in text-books is seldom seen. Taking the all-over admission in three years, only one victim of coal gas poisoning exhibited the "typical" cherry-pink colour, and this case was also complicated by the fact that she had taken an overdose of barbiturates. It is interesting to note, that this was remarked upon in a recent American Journal[11.] when the authors stated, "the so-called cherry-red appearance of the skin has not been observed/

observed although commonly the patient has a moderately flushed face".

At autopsy there is no doubt, however, that the blood and organs are a cherry red colour[184.] contrasting vividly with the normal cadaver. There is congestion of the whole cerebrum and its membranes which is more marked than that which follows asphyxia from other causes, for in the latter case the congestion is venous, whereas in gas poisoning it involves both veins and arteries so that the cut surface looks as if it had been stained with eosin, the lungs, spleen, intestine, heart and muscle all being intensely congested.

SYMPTOMS - THEIR ORIGIN AND TREATMENT.

In 1910 Hirt[117] expressed the view which was quoted by Jaksch when he said rather sweepingly, "I feel that all gas workers suffer from affections of the stomach produced by constant inhalation of small amounts of illuminating gas". Alimentary symptoms were a predominating feature in survivors of the Crarae Disaster[75] of 1886 when two or three of these survivors vomited coffee ground material. Without exception, all cases admitted to our ward had mild alimentary upsets, although only two developed after effects. In almost every case, vomiting was the symptom which caused the greatest distress. Nausea was next most frequently complained of, followed by retching and abdominal pain, with complete blunting of appetite for anything from a few days to weeks.

It would take many years to assess the degree of gastric invalidism produced in those who are known to be exposed to hazards in industry and in those who suffer from minimal gassing accidentally. I contacted a large engineering firm in order to discover the number of workmen who had developed symptoms following repeated attacks of gassing. The firm in question is served by a factory doctor, and no known cases of ill effects from gas poisoning had been reported but I had in my possession full medical reports of three workmen who had left this firm at different times as "the work was getting too much for them". Although they had deteriorated

physically/

physically, neither these patients nor the factory doctor had associated their chronic ill health with repeated gassing. If three men out of approximately a hundred and eighty working at a similar job were discovered, surely many more cases must be hidden in the country, a burden to the doctor and, more particularly, to their families from inability to fulfil their duty as breadwinners.

In domestic and industrial life, carbon monoxide is rarely met with in the pure form used in animal experiments in the laboratory. Edinburgh, as shown in Table 1 , supplies a coal gas which is carbon monoxide, plus methane, plus a multitude of unsaturated hydrocarbons. It is important to note at this stage, that Henderson in 1922 when gassing dogs with pure carbon monoxide and then with coal gas, found nausea and vomiting lacking in the former group whilst it occurred in the latter group.[108] Surely then, the hypothesis can be made, that the substance inducing alimentary symptoms in gas poisoning is not carbon monoxide itself, but the other constituents, and that the variation in symptoms may be accounted for by the variation in the composition of the coal gas. Although in nearly all standard text-books headache is stressed as an outstanding feature, surely the fact that in this Edinburgh group of cases recovering from severe or mild exposures to coal gas, this symptom was completely absent, fits in with this hypothesis.

As the origin of these alimentary symptoms

is/

is so uncertain, it is not surprising that at present little relief can be given for them, apart from gastric lavage in the acute stage in order to remove stomach contents. This also prevents further aspiration of vomitus in a comatose person.

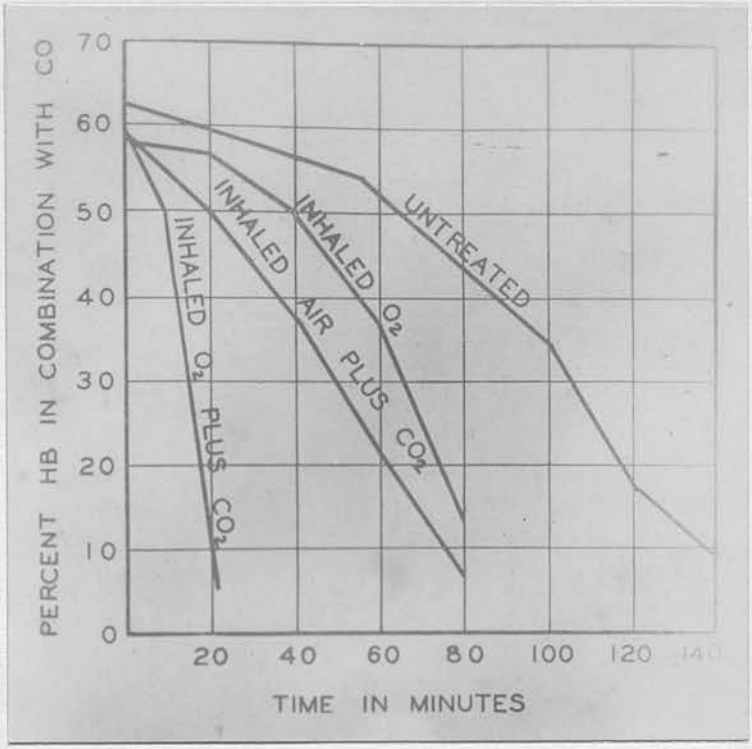
The complexity of the regulation of respiration is not lessened by the study of the effects of coal gas inhalation. Haldane in his heroic experiments showed that his respiratory rate was not increased by the inhalation of carbon monoxide until the blood saturation had reached 40%,[40] and, even then, the increase was slight. This is in accordance with the subsequent findings of Sayers and Davenport and of Killick; others observed dyspnoea only when the saturation reached 50%.

Gray[90] recently stated that the increase in ventilation caused by the action of anoxia on the peripheral chemo-receptors is not accompanied by a corresponding increase in metabolism. As a result, acapnia develops. Furthermore, this acapnia is a primary CO_2 deficit and as such, induces a fall in the arterial H.ions. Both acapnia and alkalaemia induce effects on ventilation which inhibit the anoxic stimulation. As a result of this powerful opposition, only a limited respiratory response can develop in anoxia. Increase in respiration is not, therefore, a presenting symptom until a saturation of over 40% is reached. At this stage, giddiness, inco-ordination, diminution of sight and hearing are the/

the over-riding considerations.

The rate of elimination of carbon monoxide from the blood in a given period after exposure, varies directly with the initial saturation; and it appears the same for the same range of saturation i.e. it is the same between 25% and 20% almost regardless of whether the initial saturation is 35, 30 or 25%. With an initial saturation of 35% it requires ½ hr., to fall to 30%., 1 hr. to 25%., 1½ hrs. to 20%., 2 hrs. to 15%., 2½ hrs. to 10%., 3-5 hrs. to 5% i.e. approximately 11 hours to fall from 35% to 5%.[182.] Removal from the noxious atmosphere alone, is not enough, for the patient breathes shallowly, the respiratory centre lacking its natural stimulus, thus the tissues continue to be asphyxiated - oxygen alone is not adequately inhaled. Stadie and Martin[195.] summed up their experiences thus, "Despite the presence in the blood of two or three times the amount of oxygen necessary for normal tissue function, profound anoxia results in carbon monoxide poisoning." This is due to the alteration in shape and position of the oxygen dissociation curve, causing a marked lowering of the partial pressure at which oxygen is available for tissue metabolism; carbon dioxide inhalation should act in a manner exactly opposite to carbon monoxide, shifting the dissociation curve to the right and promoting oxygen release. This lowering of the partial pressure at which oxygen becomes available might well account for sequelae found to be present following/

Plate VI.



Dissociation Curves of Carboxy-Haemoglobin.

Henderson, Y., Haggard, H.W. (1922)
J.A.M.A. 79, 1137.

following the sudden acute attack of poisoning. The patient is asphyxiated suddenly and becomes comatose from pure oxygen deprivation and unless very rapidly resuscitated, further damage may occur in the tissues with subsequent sequelae.

Since Claude Bernard,[24] in 1857, discovered the manner in which coal gas affected the body (the carbon monoxide replacing the oxygen in the haemoglobin carrying radicle) causing an anoxia, it was the established treatment to administer oxygen, but in 1920 Henderson and Haggard revolutionised treatment by suggesting that an oxygen/carbon dioxide mixture should be inhaled in a ratio of 90% to 10% (Plate VI).[109] The value, clinically, of this mixture was seen in the reduction of deaths in New York City from gas poisoning, following the use of 93% oxygen and 7% carbon dioxide mixture from 80 out of 918 in 1926 to 19 out of 791 in 1933.[64]

1% of carbon dioxide produces a detectable effect on the respiratory ventilation and as the percentage increases, so the ventilation is increased at an accelerated rate, until the maximum of 50-60 litres per minute is recorded with 9%. 5% carbon dioxide is well tolerated but higher percentages become increasingly distressing causing headache, apprehension, disorientation and finally narcosis.

The increase in pulmonary ventilation produced by exposure to carbon dioxide is a compensatory response, which protects the body from the/

the toxic effects of this gas. If there is no compensatory hypernoea - a state of affairs which may arise when the respiratory centre is deeply depressed by anoxia, the carbon dioxide approaches narcotic levels. Thus there would seem to be a distinct danger in the indiscrimate use of the oxygen/carbon dioxide mixture.

There is only one practical method of determining which gas should be used, and that is by trial and error. In order to prevent the development of sequelae, we wish to eliminate the coal gas as quickly as possible, so that the oxygen/carbon dioxide mixture is given for a period of three to four minutes. We know by experience that a response usually occurs in this time. If there is no improvement in pulmonary ventilation then pure oxygen is given and a further trial of oxygen/carbon dioxide mixture is made twenty - thirty minutes later.

First Aid workers are responsible for initiation of treatment and, therefore, would be well advised to give oxygen only, to comatose gassed patients. I believe our Fire Services are now adopting this procedure, although there is no accord between the various First Aid Societies. (The St. Andrews Ambulances visiting the Infirmary daily, carry only carbon dioxide cylinders).

To reduce oxygen consumption absolute rest is necessary whether the carboxy-haemoglobin is 7% or 50%/

50%. Early cases will recover spontaneously on removal from the poisonous atmosphere but First Aid Squads should be firmly taught that the patient should not be exercised. Muscular activity markedly increases the speed of elimination but this is not an advisable procedure for it means increased consumption of oxygen and this increased demand causes more serious damage such as irreversible changes in the heart. Therefore, the need for complete inactivity must be emphasised and protestations that the victim can walk must be strongly resisted.

Drinker, Cannon and others[105, 127, 109.] found increased moisture in the lungs of victims of severe coal gas poisoning and signs of the same in the lungs of unconscious subjects, almost 10% of the latter developing pneumonia.[40.] Although coal gas is assumed to be non-irritating and has no direct effect in the lungs, the severe case has usually been unconscious for some considerable time and has suffered shock and fall of body temperature. Loewy reasons that the impoverished blood supply to the lung fields, by the formation of carboxy-haemoglobin, destroys in part the bactericidal action, permitting pathogenic organisms to multiply; that there is such a loss of bactericidal substances has also been shown by two Russian experimenters.[49.] During the recovery phase in cases where vomiting is present there is a constant risk of the development of an aspiration pneumonia and it is imperative, therefore,

to/

to see that frequent changes of position are maintained and hypostasis avoided. Many German authors concur with this aspiration theory[21,123,172], but there is a third group who also maintain that coal gas has a direct toxic effect on the vagus with subsequent paralysis.[160]

Whatever the aetiology, the physician's main task it to forestall a bacterial invasion of virulent or commensal organisms in the embarrassed lung fields. Of late it has been the custom to use antibiotics prophylactically. Actually Sandall in 1922, studying the late effects found evidence of emphysema and chronic bronchitis or both in 46% of cases. It is interesting to note that by enlightened methods of nursing and the use of anti-biotics, respiratory complications have dropped to 6%.

The brain suffers more readily than other tissues from anoxia giving rise, in some cases, to permanent after effects, it would seem to me that the oxygen inhalation previously mentioned, should be supplemented by raising the foot of the bed on high blocks thus increasing the cerebral circulation. A further contribution has recently been published with reference to aiding the cerebral asphyxia. The correspondence of damaged areas involved with the distribution of branches of an artery suggested that a vascular disturbance was at the basis of coal gas poisoning. In animals subjected to anoxia, there is first a transitory vaso-constriction/

constriction followed by vaso-dilation. The latter state has been a prominent finding at autopsy.[188, 43.] In order to hasten recovery and prevent the primary arterial spasm and cerebral anoxia, Olsen et al[165.] injected procaine hydrochloride intravenously, as did Justin-Berancou[23.] and Larouche. The former physician's results are confirmed in a small series, while in the latter they reported "some improvement" in a few cases. The latest experience of Olsen[165.] in April, 1949, was in twenty three patients who, because they failed to respond spontaneously within the period of observation, were given intravenously procaine hydrochloride. Seventeen made a rapid recovery during, or soon after, the intravenous injection of procaine. Unfortunately, little detail can be gleaned from the evidence so far presented, making a critical assay of this work impossible.

My interest was aroused by the fact that, in experimental animals, there occurs in gas poisoning a splenic barrier - a short circuiting of the blood from the arterial to venous side without passing through the splenic pulp. This constitutes a valuable reservoir of uncontaminated red blood cells to the extent of 500 cc. of blood, i.e. by a minimum of two million cells.[14, 38.] Taking the normal haemoglobin level as 14 gms. per 100 cc., this constitutes a potential reserve of at least 70 gms. of haemoglobin, providing the patient is not anaemic. This fact is commented on also by McNally who states that an animal at rest could breathe an atmosphere sufficient/

sufficient to cause a general circulation carboxy-haemoglobin of 20% without alterations of the red blood cells in the splenic pulp. Other authors concluded that 8% carboxy-haemoglobin was sufficient to cause splenic contraction.[51.]

In an atmosphere which received a continuous supply of coal gas, guinea pigs from which spleens had been removed died sooner than the normal guinea pigs or controls which were operated on; it is also shown that there is a fatal percentage saturation which is approximately the same for all groups, but that under the circumstances of the experiment, it is reached sooner in splenectomised guinea pigs than normal animals. In rats, the inhaled carbon monoxide revealed a much lower concentration in the splenic blood than it did in the general circulation,[50.] adding further evidence to the hypothesis that the spleen acts as a reservoir for red cells shunted off from active circulation.

In 1925 the same experimenters[16.] developed new methods for studying the spleen in living dogs and cats and demonstrated the following points:

(1) That the living spleen may contain several times its volume at post mortem.

(2) Haemorrhage and exercise produce splenic contraction so that 6-12% of the blood volume may be added to the active circulation.

(3) The former condition causes the spleen to contract early.

(4) The splenic blood is richer than the systemic in red blood cells.

(5) /

(5) In human experiments on R.L.W. and R. McI. a different reaction was shown to haemorrhage - it was postulated that R. McI. lacked the trigger mechanism of exercise to fire the splenic contraction.

It is therefore possible that excess of cells is released from the spleen while the remainder of the increase in the blood volume (i.e. plasma) is secondarily derived from the tissues.[214.]

From the above summary and from the human experiments in particular, there is not sufficient evidence to presume that the splenic pulp always releases its valuable cargo. If this be the case, surely every victim of coal gas poisoning who is suffering from asphyxia due to the carboxy-haemoglobin combination should be prescribed any drug which will cause splenic contracture. Adrenaline is the drug of choice. Grollman[95.] states that carbon monoxide anoxia stimulates adrenaline secretion. No further communications are available with regard to this secretion but its bearing, with relation to splenic contracture, is important, and in addition it has been recorded that in acute carbon monoxide asphyxia, the heart rate begins to increase before an increase in respiration is apparent. Haldane[191.] recorded a pulse rate on himself of 91 per minute with carboxy-haemoglobin of 16% and of 104 per minute with carboxy-haemoglobin of 40% with beginning dyspnoea.

Killick,[122.] however, recorded a pulse rate of -

56.70/min. at 25% or under.

65.80/min. at 30%
70.95/min at 35%.

I would suggest that adrenaline secretion may be responsible for tachycardia developing in the absence of respiratory increase and may be the key which opens the splenic locks and floods the circulation with uncontaminated red blood cells.

We do not know the point exactly at which the spleen contracts nor when tissue damage becomes irreversible, making the production of sequelae inevitable, but surely all cases should be treated so that they might benefit from this store of uncontaminated blood.

In the light of our present knowledge of the pathogenesis of coal gas poisoning, treatment, therefore, must consist of immediate rest from the time of discovery, with inhalation of O_2 or a mixture of 93% oxygen and 7% carbon dioxide. Particular attention should be paid to shock with high elevation of the foot of the bed and frequent changes of posture and prophylactic use of Penicillin. Injection of Adrenaline should be considered, in the patient showing little recovery under routine treatment.

Plate Vll.

TABLE 3.—*Incidence and Type of Neurologic Lesions Occurring Following Carbon Monoxide Poisoning*

1. Number of cases showing muscular hypertonia (increased reflexes, perhaps clonus and positive Babinski) (1 shows signs after 2 yrs.)	9
2. Number of cases showing hypertonia and some degree of peripheral neuritis (2 permanently)	5
3. Number of cases showing parkinsonism (3 permanently)	4
4. Number of cases showing parkinsonism and some degree of peripheral neuritis	1
5. Number of cases showing only peripheral neuritis	4
6. Number of cases showing no neurologic signs	10
7. Number of patients dying before complete neurologic examination	10
Total	43

Shillito F.H., Drinker C.K., Shaughnessy T.J.

SEQUELAE AFFECTING THE CENTRAL NERVOUS SYSTEM.

The results of the enquiry showed that 1.28% of those who attempted suicide by coal gas poisoning, but failed to kill themselves, developed neurological sequelae whereas 27.02% of those accidentally gassed developed sequelae.

As the neurological system is picked out most frequently, I have divided the sequelae found into two groups - (i) where the central nervous system is affected

(ii) sequelae affecting other systems.

Glaister and Logan[175] writing in 1914 said, with reference to the nervous system involvement following gas poisoning - "Much has been written by French and German authors but in our country, judging from the Report of the Departmental Committee on Compensation for Industrial Diseases, very little appears to be known. Only four cases were brought before the notice of that Committee, two by Sir Thomas Oliver and two by Dr. J. Bing and, as a result, the Committee remarked that, had a gas such as carbonic oxide possessed noxious qualities of this character, they would have expected that the fact would have been recognised long since and in many more than four cases".

As time went on doctors were on the look out for sequelae and series after series of cases were reported from many sources.* The Plate VII shown on the opposite page is the compiled work of Shillito, Drinker and Shaughnessy.[190] Other published single cases/.

* [7, 18, 19, 38, 80, 115, 138, 190, 204, 238

cases showing such diverse sequelae as parkinsonism,[93] polyneuritis,[180] choreiform movements,[151] neuroretinitis,[216] optic atrophy,[30] psychomotor disturbances,[171] loss of smell and taste,[29] and retention of urine and faeces.[79]

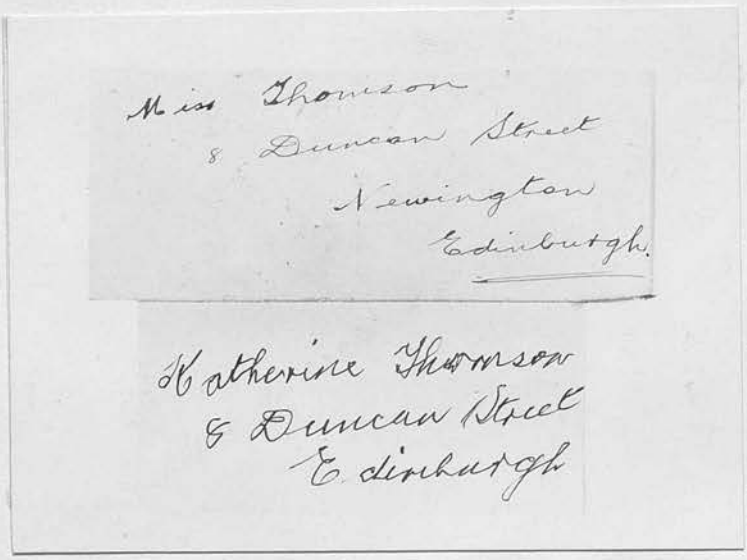
The figures based on my enquiry agree with the above findings which show that neurological affections contribute the most important sequelae to coal gas poisoning.

This affinity of coal gas to produce lesions in the central nervous system was confirmed experimentally by Lewey who exposed dogs to a carbon monoxide mixture for five and a half hours each day for six days each week for eleven weeks. Blood saturation was never higher than 20% but the dogs showed a consistent disturbance of posture and position, reflexes and gait. These effects were not marked clinically, and the dogs retained a friendly disposition throughout. Subsequent histological examination showed changes in their cerebral grey and white matter and in their heart muscle.

I present the following clinical evidence in support of a neurotoxic factor in coal gas.

The degree and type of neurological lesion vary from case to case and many are described.[131] Regardless of the nature of coal gas poisoning, the gas, when inhaled, it is said, may produce symptoms immediately, or weeks after exposure i.e. following a "clear" period.[86] Although copied and reproduced from book to book, does this clear period, when the patient is entirely/

Plate Vlll.



SPECIMENS OF HANDWRITING.

entirely sign and symptom free with no evidence of pathological disturbance, actually occur?[7]. It must be remembered that a labourer will rarely notice a fine tremor of a hand whereas a clerical worker would do so immediately.

The point is clearly illustrated by the following cases:-

> Miss K.T. aged 66, was found in the shop where she worked, having been overcome by gas fumes which had leaked from a fractured main pipe in the street. She was conscious on admission to hospital. Carbon dioxide and oxygen inhalation was given and she made a rapid recovery, and at the time of her discharge no abnormality was detected. I examined her following her reply to the questionnaire, in which she said that her hands were shaking. When questioned carefully with regard to her writing which in the questionnaire was very shaky, and typical of the 'Parkinsonian Type' she admitted that it had deteriorated rapidly following her return to work after the gassing. Her writing, before and after the accident, is shown opposite (PlateVIII) and is ample witness.
>
> On examination I found that she had a rhythmic tremor of the right arm and hand which ceased temporarily on voluntary movement. No other abnormality was detected.

Had this symptom occurred in a patient not concerned with manual dexterity, then quite definitely a long clear period would have been recorded, I would, therefore, define the clear period in broad terms as being the interval of time prior to recognition of pathological signs or symptoms.

The second illustration of this misconception of

a/

a clear period is shown by the following case:-

> Mr. W.H. aged 49, was admitted with involuntary tremor of the right upper and lower limbs with some rigidity and with an emotionless face. A diagnosis of a right hemi-Parkinsonism was made. The etiology of this was found in his occupation of three years previous, when he was a fitter-engineer to coal gas holders.

Two points emerge from this case:- that although his chronic exposure to coal gas had ended three years before and during these three years, he had been living in the country, the tremor and rigidity, our yardstick in the diagnosis of Parkinsonism, had been present only for a few months. A careful cross-examination of his family revealed that there had been a change of personality during the last three years. It was slight and unnoticed by those outside the family circle, yet sufficient to make him give up his trade and take up the less arduous task of tending pigs in the country. A physician, seeing this man three years ago, could not appreciate the finer points of alteration in his psyche, and he would now be classified as suffering from Parkinsonism following a clear period of three years - three years which were not symptom-free but three years before the onset of a recognisable clinical entity.[33]

At autopsy patients who have survived the acute attack of gas poisoning or have been subjected to chronic poisoning are found to show a characteristic pathological softening of the anterior portion of the pallidum/

pallidum on both sides which has been discussed in Chapter 111. The softened area may vary in extent on the two sides with correspondingly more severe rigidity on the side opposite the larger lesion.[93.] This is exactly what was observed in the case of Mr. W.H. The gross clinical entity of hemi-Parkinsonism affected the right side, while observation over a six week period made it evident that minimal rigidity and tremor were present in the left lower limb, varying greatly with the mental state of the patient. As this fleeting but sufficiently convincing evidence of involvement of his left side, in keeping with pathological studies, was recorded I felt even more strongly that the clear period was a misnomer. Many other cases are similar to this and can be included in this group.

> Mr. P.G. aged 62, who was slowly rendered unconscious by the leakage of coal gas from a faulty street main, was unconscious for approximately three hours before he was discovered and sent to hospital. He made a rapid recovery with carbon dioxide and oxygen inhal-:ation, was in bed for fourteen days and convalesced for a further seven days. No abnormality was detected in the Central Nervous System. The first symptom occurred when he failed to maintain his balance while "strap-hanging" in a bus, some weeks later. Previously he had always had good "sea-legs". He then found that only with difficulty could he walk heel-to-toe along a straight line. Examination revealed no neurological pathology.

This case, too, might have passed as symptom-free for some time and have been alleged to show a clear period.

There are, however, some cases which do show beyond all reasonable doubt a sign and symptom free period/

period. They will be discussed in Chapter Vll.

Finally I wish to draw attention to Table 5. and in particular to the broken column representing the unknown number of those poisoned by coal gas. If it runs parallel to the second column, sequelae, predominantly affecting the nervous system, will emerge from its ranks. The Americans have been worried about this large unknown entity. As referred to in Chapter lV , during the winter of 1948-49 thirty-two persons suffering from coal gas poisoning were admitted to the Neuro-medical Unit of the Los Angeles County Hospital. A number of these patients gave a history of symptoms indicating previous exposures. In only nine cases had a correct diagnosis been made prior to the acute and more obvious anoxial episode that led to their admission. The initial diagnosis made before a history could be taken was often incorrect even in the case of acute anoxia. Among the initial erroneous diagnoses were schizophrenia, hysteria, syncope, food poisoning, epilepsy, expanding intra-cranial lesions. It seems likely, therefore, that many cases of acute and chronic anoxia due to inhalation of coal gas go unrecognised.

From the questionnaire, those suffering from sequelae can easily be ascertained but sequelae developing from the unknown suicides and the untreated accidentally gassed, will forever be unknown. In these ranks may lurk the minor maladies and psychoses

so/

Plate 1X.

Mr. A.W.

so frequently complained of by patients and labelled as neuroses.

In this series of cases, ten patients exhibited neurological sequalae and four of these illustrate the hypothesis that psyche is affected predominantly when the gassing is acute, in other words, when there is rapid asphyxia; in effect two of these cases were suicides, one accidental poisoning and one misadventure. Common to all was the fact that they were subjected to a sudden high concentration of coal gas.

> On 9.1.48 Mr. A.W. aged 14 years was found unconscious in the kitchen with all taps of the gas oven turned on. He does not remember the incident. He remembers going to the school in the morning but not coming home that day; neither did he know what had happened at school.
>
> On admission to the ward his general condition was quite satisfactory. He was regaining consciousness rapidly but resisted examination. He would not answer questions unless repeatedly prodded to do so. He was incontinent. There was no rise of temperature, the pulse was elevated but became normal within 48 hours. There was no subsequent rise of temperature. During the ensuing week he was confused, disorientated and remained dirty in his habits. He was sent to Jordanburn for fuller investigation of his mental symptoms and while there it became evident that his personality had undergone a marked change. He became forgetful, confused and extremely quiet. His mother stated that, until the gassing incident, he was a perfectly fit boy and lived a full life, with cycling football and Scouts as hobbies. He got on well with other boys and was a popular goalkeeper, and he had/

had special tuition in boxing. He was in the middle of the class at school, and worried a great deal over his homework. According to a previous headmaster's report (Tynecastle School) he was a steady worker, with an I.Q. of 104 and was a likeable boy and always "full of beans".

In the house he helped his mother a great deal. He has one elder brother with whom he gets on well, and a younger sister.

The mother believes that he was unconscious for about 3-4 hours. On recovering, he recognised his parents but was dazed and expressionless. He had no memory for events past or present. He did not know the day of the month and had no idea of time. He could not say whether it was day-time or night-time.

He had an operation when he was 12 years old, in the Sick Children's Hospital and he thought he was back in this Hospital. Gradually in Jordanburn his mental state improved but there was only minimal evidence of intellectual improvement.

Gradually over a period of 6-8 months he began to know the time of day and events in his past history came back to him clearly and correctly; there has been no return of recent memory, even up to five hours prior to his accident. His general interest in life has faded - football, Scouts, cycling etc., hold no pleasure for him now, mainly because he is unable to concentrate on one subject for more than a few minutes. He was very happy at school prior to the accident and wished to return (i.e. after an absence of six months). After his return to school his headmaster reported that the boy had changed completely. There was a complete inability to concentrate "things slid out of his mind" - he was unable to read and absorb even the headlines of the papers. He would work for five minutes - no longer. Daily, he realised that he was mentally backward and that his younger sister was cleverer/

cleverer than he was. This is now giving him an inferiority complex and he is unwilling to mix with his previous friends. He is in no way wicked, but sits about the house, going to bed at 7 or 8 p.m. He plays childish games, his sister mothering him continuously and as soon as he was 15 years old he left school having made no progress, intellectually. He held the job of a plumber's apprentice for a few days only and then started work as a help to a bakery vanman. He is well liked and is happy in this job but he is quite unreliable and all orders have to be written on a piece of paper e.g. one of his jobs is to fill the car radiator with water every morning. If he is not reminded five minutes beforehand, it is never done.

Physically he is a sturdy youth. There are no abnormalities to be elicited in the central nervous system. Incontinence followed the accident for 12 months and finally stopped completely within 18 months. His previous history gives no evidence of bladder dysfunction. Of recent weeks he has taken much more interest in himself. He washes his face and gets his hair cut without being told. From time to time he develops tics, such as eye-twitching, spitting, nail biting or tapping with his feet. The latest develop-:ment also, is the fact that the least irritation makes him flare-up into an aggressive temper. He uses his fists at the slightest provocation. This never occurred prior to the accident.

Mr. C.H. aged 43, was apparently in good health and at his work, until he tried to gas himself during the morning of 23rd August between the hours of 6 a.m. and 6.50 a.m. when his wife found him unconscious, his head in the gas oven with windows and doors shut. She put him to bed but did not call for assistance as she fully realised/

realised his reason for committing suicide; within five hours he opened his eyes, did not speak but obeyed commands; by 3 p.m. he was able to answer 'yes' and 'no' and she noticed that the left arm and leg seemed weak. He remained in bed, not speaking voluntarily for a week; suddenly power returned to the left limbs and within three weeks he recognised his children, although still confused. A month later he was quite fit physically apart from slight weakness of the left arm and dorsi flexion of the left foot. He was then admitted to hospital. On examination he looked depressed but had little depressive thought content. His face was immobile. Organic mental functions were very seriously impaired, both for recent and remote memory. His conversation ran something like this:

"Dr. Q. How are you?

A. Bl...y awful. I feel bl...y awful.

Dr. Q. How is that? Explain it to me.
A. You want to do something bl...y awful to me.

Dr. Q. Not that I am aware of.
A. Why are all the thugs in here?
Q. Who are the thugs? Just tell me all about it. Explain it to me.
(This was repeated with no answer).
A. Well, it doesn't seem like a real hospital. No, it does not.

Dr. Well you come on and explain it to me so that I can understand.
A. It does not seem like a hospital.

Dr. Q. What does it seem like instead?
A. An asylum.

Dr. Q. Well, what about the thugs and things?
A. You are a thug.

Dr. Q. Why do you say that?
A. You are the thug.

Dr. Q. Why do you say that?
A. Why am I all trussed up in here? etc....

He then demanded to be taken home, when in a few weeks, his family doctor/

doctor warned his wife that he was suspicious of everybody and was becoming obstreporous, aggressive and dangerous, he was committed fully to a Mental Hospital. His family doctor said he was allowed home four to five months later much improved physically and mentally though he is still unfit for work. He acts automatically and only does as he is commanded, otherwise he stands about with a vacant expression on his face. There is a possibility that he may at some future date manage light work under supervision.

Mr. D.F. aged 61, was found unconscious on a retort of the local gas works, his clothing reeking of coal gas. He was taken to a nearby hospital and allowed home although still very confused. He remembered nothing of the events leading up to this attack but it was presumed that he was overcome by leaking coal gas fumes while in the course of his duties, collapsing on to the retort, where he was later found.

In the evening, after he had arrived home he complained of bilateral blindness. He was admitted to the Royal Infirmary, Edinburgh, where a careful physical examination revealed no abnormality; nothing untoward was found in the eye grounds to account for his blindness and at that time there was justifiable suspicion of his being able to see more than he would admit. His eyesight recovered fully in the next few weeks. There is little doubt that these symptoms were psychogenic in origin induced by the anoxic encephalopathy of coal gas poisoning.

Mr. J.R.M. aged 35 years, obtained work in Edinburgh as a labourer in July. Following this new occupation, he began to feel sensitive and blush when spoken to. He formed the opinion that his mates talked about him, whispered and scoffed behind his back. He left this job but was directed back there following 6 weeks' idleness, by the Labour Exchange. He went to bed that night apparently normal and was found at 5 a.m. unconscious with his head in the gas oven/

oven. The gas meter was of the 1d. in the slot type. His mother had put in 1d. to boil a kettle of water; it was concluded that only a limited amount of gas was available. He regained consciousness an hour or two after admission and remained there for a fortnight before he was certified and transferred.

During the intervening days be was confused; would hardly answer when spoken to and just repeated the question. He was disorientated for time and place and seemed not to recognise common objects. When offered food, he did not seem to know what to do with it, and was spoon fed. He became doubly incontinent. He sang hymns and failed to recognise his mother and sisters. His mother formed the impression that he seemed to look at her and could not see.

Following admission to a Mental Hospital his incontinence cleared up, but he remained bewildered and perplexed, never speaking unless spoken to and looking strange and vacant. He answered slowly, in a hesitating voice; his memory and orientation were grossly impaired.

Progress

Within the next two years he showed progress in his ability to adapt himself to his environment. Thus he is much more able to perform simple calculations, and to recognise common objects.

Although on the whole, he is bright and happy and able to go out with his friends, he has considerable insight into his difficulties; this upsets him and he becomes despondent and irritable; there is some emotional instability still present and he easily laughs and weeps. Much improvement has taken place but he remains seriously involved organically and deterioration is of such a degree that he will have to remain under hospital supervision.

In these four cases, acute coal gas poisoning has produced in one case, short lived psychosis, while/

while in three, permanent organic cerebral deterioration; and in these latter three cases the confusion began immediately, on recovery from unconsciousness. In Professor Sir David K. Henderson's experience there is usually a clear period following the gassing, the psychosis developing after a latent period of fourteen to fifteen days; in some cases it is a few weeks before they develop severe katatonic symptoms. This is of interest because it is similar to what is seen prior to post-encephalitic Parkinsonism and indeed the "clear" period between gassing and the development of organic physical signs.

A second striking fact emerges from three of these cases; their complete reversal of disposition and personality.

In Case 1 before the accident a normal, inoffensive boy who is now quick tempered and aggressive.

Case 2 a normally behaved, amiable man, trusted secretary of a men's club before his gassing, now suspicious, obstreperous and aggressive.

Case 4 a shy, rather pathetic and depressed young man of the schizophrenic type, who, following his accident, is euphoric.

This fact indicates that the psychotic sequelae in these who have suffered from rapid coal gas poisoning is predetermined by their former personality. In these cases it would seem that they are/

Plate X.

Globus pallidus
Infarction.

Disseminated Sclerotic Plaque.

BRAIN section of Mr. W.G.
suffering from Disseminated Sclerosis,
complicated by coal gas poisoning.

are diametrically opposite to that disposition.

These cases are similar to anoxias produced experimentally in cats and dogs and one would expect that the pathological findings would be similar to that in any case of cerebral anoxia, leading to a diffuse disorder involving the whole of the cerebral apparatus with a tendency to partial recovery.

The remaining patients who ~~had~~ complained of sequelae had been slowly gassed and their clinical evidence supports my contention that the lesions in the brain in cases of gas poisoning which have taken place over a considerable time, are not wholly anoxic in origin.

In reviewing cases which have suffered from previous anoxia of one area of the brain, it might be concluded that, should the brain be subjected to gas poisoning, the next area to be affected -(If gas poisoning purely produced anoxia) would be in adjacent areas to the previous lesion, but clinical evidence does not support this, for example:-

> Mr. W.G. aged 41 years, previously known to be suffering from disseminated sclerosis was admitted to hospital following suicidal gas poisoning. His exposure was rapid and of one hour's duration. He died within three days never regaining consciousness.
>
> The brain (see Plate X) showed multiple small scattered plaques of disseminated sclerosis through the grey and white matter of the cortex, central white, basal ganglia, and brain stem. The cord, on section showed multiple, irregular, rather wedge shaped, yellowish areas at different levels.
>
> Microscopically these lesions were shown to be of recent origin with complete demyelinisation and relatively/

relatively little axis cylinder destruction. The degenerated myelin is present in compound granular cells. The astrocytic reaction is in the form of a well marked cellular gliosis.

On section, the globus pallidus on both sides was pale anteriorly, with many congested vessels. The brain was markedly congested especially in the deeper grey matter. There was a small area of petechial haemorrhage in the deeper grey matter. This was most marked over the parietal convexities and the temporal region. In places the grey matter had entirely separated from the underlying white, the line of separation being sharp.

Pickworth's staining on the cord and brain confirmed only venous congestion. There was no noticeable abnormality in the plaque areas, no ischaemia nor capillary increase.

It is recognised that in disseminated sclerosis the area which is attacked by the pathological process first suffers from venous thrombosis, [173,174] and vascular blocking. Hence the current use of anti-coagulants as a therapeutic measure. It is a strange anomaly in this case that, following gassing, the vulnerable areas were not adjacent to the previously anoxic areas, but still the basal ganglia and the globus pallidus and to some extent the thalamus; the latter effect is reasonable in view of the shortness of cell survival following oxygen deprivation.

It seems logical, therefore, to conclude that if anoxia were the only contributing factor in gas poisoning/

Plate XI(a)

VEHICLES of all Groups from 4th Nov 1938 until 6th Nov 1939 inclusive.

Fee of 5/- received.

THE COUNTY CLERK, Taxation Dept., County Buildings, Cupar-Fife.

Usual Signature of Licensee:

Joseph Houston

Joseph Houston

Longdykes

Leven

poisoning, then the parenchyma surrounding the disseminated plaque would have been selected for further damage.

> Mr. W.W. had pre-existing damage to the basal ganglia in the form of post encephalitic parkinsonism. The disease was progressing slowly and he was bilaterally affected with rigidity and tremor. Mentally he was relatively alert and was able to carry on a job as a paint mixer. During a depressive phase, he attempted to take his life by inhaling coal gas through a rubber tube. His wife found him unconscious but on admission to hospital he was semi-conscious, with a blood carboxy-haemoglobin concentrat-:ion of 35%. He made a complete recovery over the next few weeks. It is natural to suppose that his Parkinsonian symptoms would suffer an exacerbation. They did not and after nine months have shown no signs of so doing; there was no evidence to suggest that the recent gassing had produced any further damage to the already damaged basal ganglia. The attack was short and sharp and in the nature of a pure anoxia.

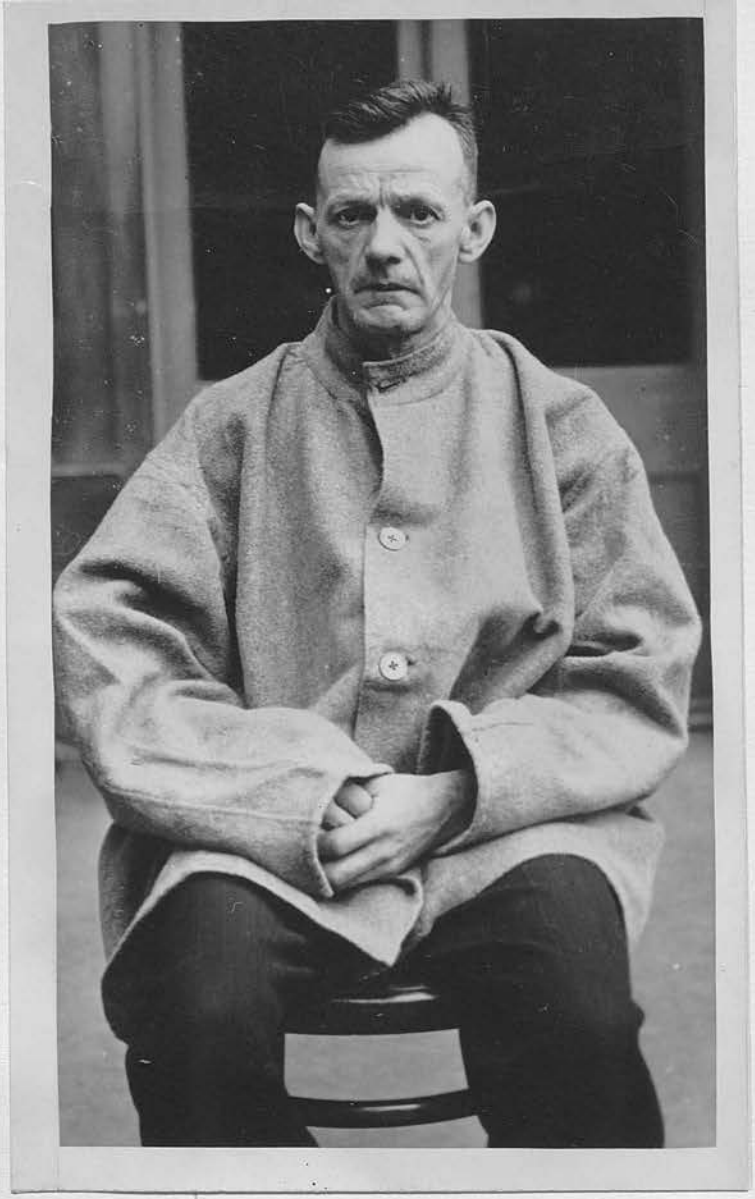
It would appear from many cases subjected to gassing over a long period of time that the soma and not the psyche is predominantly involved.

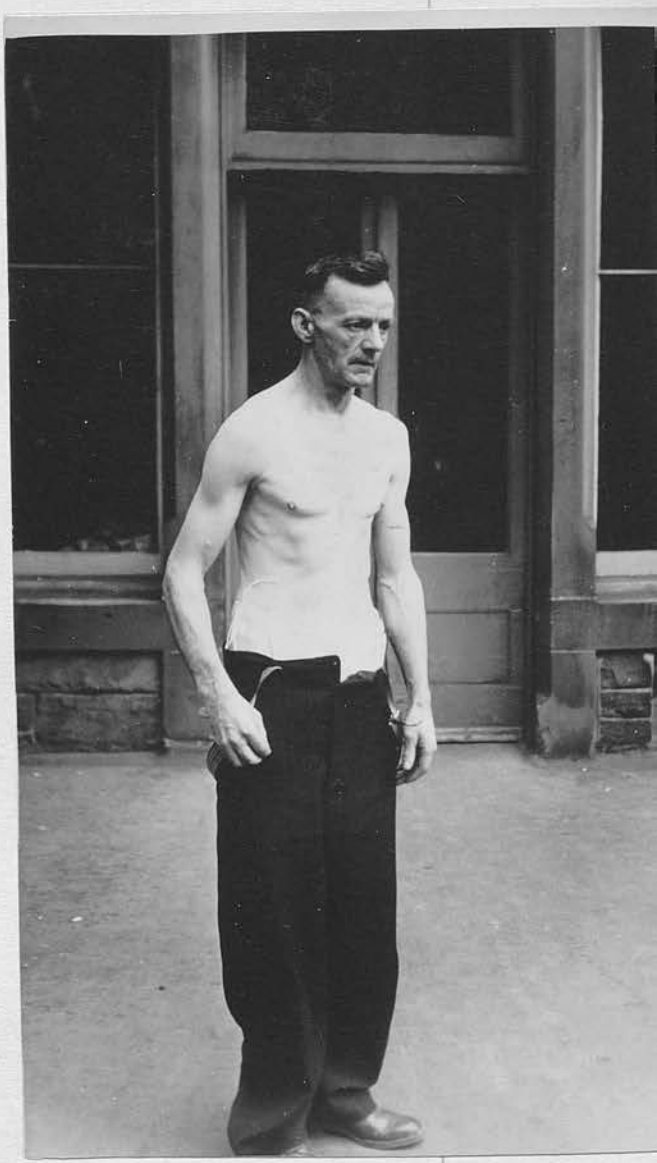
The following six cases illustrate this.

> Mr. J.H. aged 49 years, had felt dizzy at his work on many occasions, while mending gas pipes. From the table 7 on page 66, it would seem that his carboxy-haemoglobin would be approximately 10-20 % at the most. There was slight anoxia although not of such a degree as to make him breathless or give him palpitations. At no time did he become unconscious. He continued with his work on these occasions, after a short rest in the fresh air. There was no anoxia comparable to that seen in the acute gas poisoning of suicides - yet Mr.H. suffered severe damage to his extra pyramidal nuclei producing a progressive Parkinsonian picture.

Mr/

PLATE X1 (b)





Mr. J.H.

Mr. P. aged 73 years, was admitted to hospital having been found by neighbours in a gas filled room. The leak had been caused by a faulty meter. He remained unconscious for one and a half hours, was cold and had a temperature of 101.F. He gradually recovered with oxygen/carbon dioxide inhalation was discharged within two days, no physical abnormality being noted. His central nervous system was intact.

I saw him ten months later when he was complaining of a slowness of speech and increasing difficulty in walking. His hearing had also deteriorated markedly. Examination showed the picture of Parkinsonism, the mask face, with rigidity of the lower limbs in the ascendency, and tremor, slight. He had a complete nerve deafness. No other cranial nerve was involved. His Wassermann was negative. The diagnosis made was that of a Parkinsonism with Vlll cranial nerve involvement.

Mr. P.G. aged 62 years, was admitted to hospital, having been overcome by coal gas. Seemingly, there had been a slow leak from the gas main which percolated through the house. The gas, apparently, had lost its odour due to absorption in the earth. Both he and his wife became sleepy, sick and developed severe headaches. Mrs. P.G. went to bed where she was found later unconscious, while Mr. P.G. turned on the taps to have a bath - went to lock the front door but was overcome on the stairs and rendered unconscious. They were found in this condition about one and a half hours later by a friend who noticed their front door ajar. They were taken out into the fresh air and by the time they reached hospital were regaining consciousness. Within 48 hours they were discharged symptom-free and showing no abnormalities whatsoever.

Mr. P.G. returned to work in a few weeks and it was then that he noticed he was unable to 'strap-hang' in the bus gangway - a state of affairs which had never existed before the gas accident.

It was felt that this ataxia had its/

its origins in the peripheral nerves of the lower limbs. Rhomberg's test showed definite unsteadiness when the visual pathways were blocked. No other objective findings came to light.

In all probability Mr. P.G. had been inhaling small quantities of gas since early morning, when the lower parts of the house were being filled. The resultant high concentration had finally caused him to lose conscious-:ness.

Mr. A.T. (Junior) aged 21 years, who along with his mother and father, were slowly overcome by coal gas, over a two day period, traced to a leaking main in the street. They were all unconscious on admission. The father died within the next twenty-four hours but the son and mother survived. Although quite fit on discharge, the son exhibited attacks similar to petit mal, over the next six months. These have now entirely subsided.

During an attack he would become drowsy, feel sick and for the moment would require assistance. Recovery was immediate. He at no time attended his doctor and his mother only heard about the fits from a neighbour.

Miss K.T. aged 66 years, referred to in a previous chapter, was found in her shop, where she was working, overcome by gas fumes from an escaping main; she regained consciousness rapidly and within one hour was able to walk. She was allowed home within four hours.

Within six months, following this gassing, she noticed that her writing was deteriorating a thing which, as a secretary, she had been quite proud. Her hands were becoming shaky, especially on the right side. It became embarrassing for her to hold a tea cup for she was unable to prevent it rattling, but voluntary movement decreased the tremor. There was no evidence of spasticity in the limbs. She had no lack of emotional tone and no hypersalivation. The cranial nerves were intact, there was no previous history of intra-cranial disease or any hereditary or familial tremor.

There was no doubt that this patient/

PLATE XII.

Mr. M.G. (a)

(b)

(c)

patient was developing a progressive Parkinson syndrome with tremor of the upper limbs predominating.

Mr. M.G. aged 19 years, was unconscious when admitted to hospital, his carboxy-haemoglobin being 58%. Over a period of 7-8 hours, he had been subjected to a slowly rising concentration of coal gas, issuing from a gas fire, where the taps were loose fitting and had been accidentally turned to half-cock.

He recovered consciousness within two hours following treatment but was confused, nauseated and felt miserably ill.

The following day, he was mentally alert and fully co-operative although amnesia for events prior to the gassing persisted. (Plate XII(a))

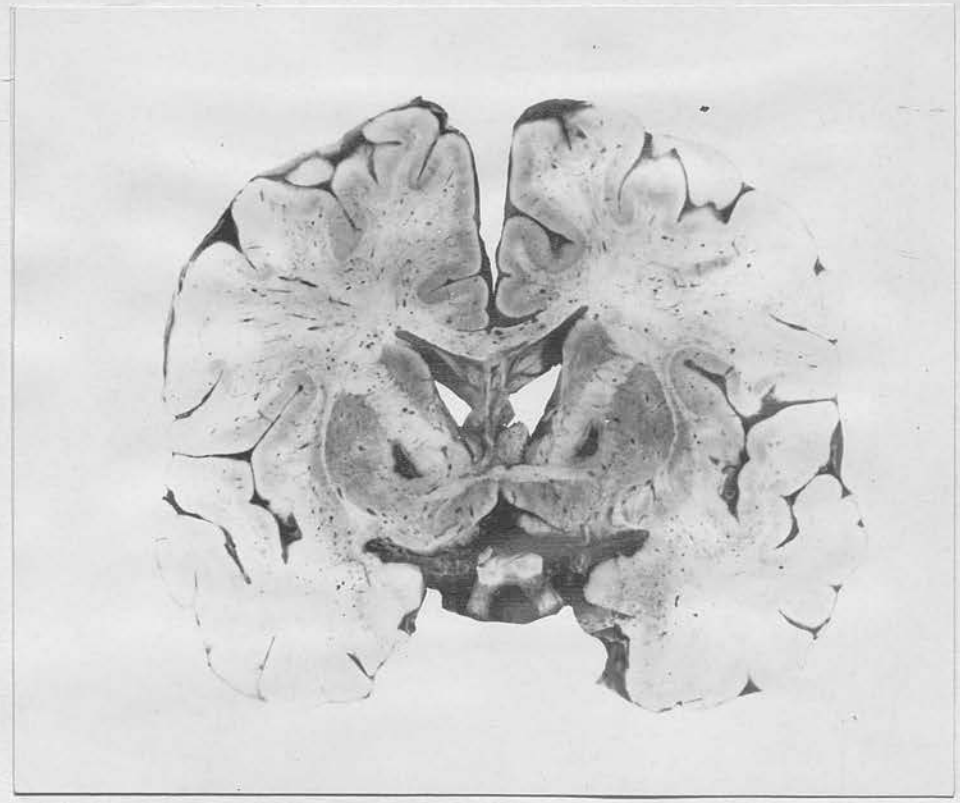
Neurological examination revealed weakness in the L. upper and both lower limbs with a left facial paresis (Plate XII(c)) There was marked hypertonicity of both lower limbs with brisk reflexes in the right, exaggerated L. knee and ankle jerks and clonus. Both R. and L. plantar responses were extensor. Abdominal reflexes were lost in their lower quadrants.

Apart from diminished vibration sense in the L. lower limb, no other sensory changes were elicited. The cerebellar tracts and cranial nerves with the exception of the L. facial paresis which rapidly subsided, were intact. A complaint of tinnitus of the R. ear was fully investigated but no abnormality was detected on specialist examination. The Wassermann reaction was negative.

By the end of the week no evidence of the facial weakness, impairment of vibration sense or any abnormality in the upper or R. lower limb could be elicited. The R. plantar response remained equivocal. Hypertonicity, with diminished motor power, exaggerated reflexes and extensor plantar response remained - (Plate XII(a)) The lower abdominal reflexes returned but were easily fatigued.

Three weeks later, on discharge, his gait was slightly ataxic, the left foot dragging slightly and circumducting with/

Plate XLII.



BRAIN SECTION
following acute and chronic gassing episodes.

with every step.
At follow-up clinics, little improvement was recorded in the affected limb, despite regular physiotherapy treatment.

These six cases were of accidental coal gas poisoning. Coal gaswas inhaled over a period of hours or even days and as a consequence the nervous system was grossly involved. That neural tissue and in particular the basal ganglia should suffer so much more severely following chronic poisoning than following the asphyxiation of acute poisoning is surely against a purely anoxic etiology.

This difference between acute and chronic poisoning by coal gas is demonstrated irrefutably by the pathological findings at the autopsy of Mr. F.W. who had suffered chronic gas poisoning, followed, three years later, by a fatal acute gassing.

The brain was congested. There was a moderately large triangular cystic infarct in the medial portion of the anterior globus pallidus, with multiple diffuse petechial haemorrhages throughout the white matter (see Plate XIII).

Microscopically, the pallidal infarct showed evidence of a little old haemorrhage. The wall was well composed of a dense glial scar in which were trapped many fat laden phagocytes. Vessels crossing the infarct and around it, showed well marked siderosis. The pathological appearances were compatible with three years' duration.

In the white matter of the temporal, parietal, occipital/

occipital and frontal lobes and in the internal capsule, there was capillary dilation and diapedetic haemorrhages. In mid-brain, pons and upper medulla none were seen. Around these haemorrhages a marked microglial reaction had taken place in the form of swelling. These changes were of short duration and had obviously occurred as a result of the acute gassing episode.

SEQUELAE AFFECTING SYSTEMS OTHER THAN THE CENTRAL NERVOUS SYSTEM

CARDIOVASCULAR SYSTEM

Although after-effects are found in the central nervous system more often than in all the other systems, the fact that other systems are permanently damaged by coal gas, must not be forgotten.

Klebs[124] in 1865 noticed for the first time that, after gas poisoning, pathological changes were found in the heart. Punctiform and diffuse haemorrhages had occurred into the pericardium, including the tips of papillary muscles. This was confirmed electrocardiographically by Colvin[42] and Kroetz[126] at a later date.

In the course of a study of large numbers of patients where illness could, unquestionably, be attributed to frequent and prolonged exposure to coal gas, Hill and Semerak[114] were impressed with the frequency of cardiac symptoms. In many instances they were chiefly functional - "However, in some cases clinical manifestations were predominantly those of organic disease". In summary, the findings of one hundred and thirty six patients showed that the lesions previously affecting the heart were vascular, consisting of small haemorrhages, perivascular infiltration and focal necrosis. Coronary thrombosis frequently developed as shown by the electrocario-:graph and post mortem studies.

This/

This was confirmed by Campbell[3] who showed that heart muscle would not tolerate a low oxygen tension, and as a result, circulatory failure supervened, with congestion, oedema, degeneration and atrophy. Americans experimenting with dogs observed petechial haemorrhages, most of them not larger than would be caused by diapedesis through the dilated vessels.[41] These animals were also subject to varying amounts of gas in the inspired air and give the lie to the impression that unless death occurs no cardiac damage will be evident.

Those surviving the delayed manifestations may recover completely or ultimately develop serious organic disease of the heart to which they finally succumb.

In my series of cases only two patients developed cardiovascular symptoms directly attributable in any way to their gassing episode.

> Mr. D.G. aged 73, was admitted in August, 1949 following accidental coal gas poisoning in his own house. Although smelling strongly of gas he was conscious on admission and physical examination was negative. He had always been a very fit man. His temperature which had been normal rose slowly on the seventh day and he developed pain in his left foot due to arterial obstruction; he was transferred to a nursing home by relatives.
>
> Mr. M.R. aged 66, was overcome by coal gas while cleaning a sewer, probably exposed one to two hours; he recovered following artificial respiration for forty minutes and when admitted was conscious and fully orientated. Careful physical examination revealed no abnormality; he/

he was discharged the following day. He had never been ill prior to the gassing.

Three weeks after discharge it was noted that his hair turned grey quite rapidly, he became exceedingly breathless and cyanosed on the slightest exertion and unable to carry on with his work. He was admitted some weeks later, to a surgical ward as an abdominal emergency. This turned out to be a coronary thrombosis. His condition rapidly deteriorated and he died within eighteen months.

It must be admitted that the thrombosis in either Case 1 or Case 11 might have occurred whether or not the patients had been gassed but previously they had both been fit men. In view of this fact it is most suggestive that symptoms developing so rapidly after the gassing attack, if not actually the direct result of the gassing, were at least aggravated by it.

The factors responsible for vessel wall damage, whether in the coronary or limb vessels, must be the same factors that damage vessels in the globus pallidus. In the case of Mr. M.R. there is sufficient evidence from the prolonged and severe anoxia to account for the slowed peripheral blood flow and in a person of the seventh decade such sequelae must always be borne in mind. The effects of such gassing will undoubtedly be of a severe grade where there is antecedent arterio-sclerosis. It would seem probable that thrombosis formation is the expression of damage to the vessel wall and would tend, naturally, to occur where the circulation is the slowest/

slowest, viz., in the small veins. The actual duration of asphyxia necessary to produce such damage has been said to be twenty minutes.[188] The findings in the case of Mr. D.G. fit in with this hypothesis.

The case of Mr. M.R. presents the possibility of a similar aetiology as to the cause of the myocardial infarction. Tessereux,[205] in 1928, was unable to find evidence of vascular blockage in a woman who died three days after gas poisoning although there was extreme necrosis of the cardiac muscle fibres. Herzog[111] summarised the pathological heart findings in eight cases of gas poisoning, and found that in patients, dying two to four days after gassing, there was hyalinisation of the muscle fibres; in two patients dying nine and twenty-three days respectively after gassing, connective tissue infiltration and formation of new blood vessels were evident. In coal gas poisoning, the heart is deprived of oxygen by the formation of carboxy-haemoglobin with consequent exclusion of oxygen. That this poisoning caused a true anoxia to the heart muscle in cats was shown by Lewis and White;[132] the most specialised tissue succumbs first, i.e. auriculo-ventricular node, sino-auricular node, and bundle of His.

Their experiments were confirmed in human beings by Greene and Gilbert,[91] who also showed that any disturbance /

disturbance below the branching of the main bundle is usually permanent - so that a previously damaged heart might suffer irreparably. In the precritical stage there is shortening of the PR interval and in the post-critical phase a tendency for the auriculo-ventricular node to supplant the sino-auricular node as pacemaker, consequently slowing the heart rate and later diminishing conductivity of the auriculo-ventricular node and bundle of His.

Pathological findings confirm the evidence in the preceding paragraphs.[96.]

The series of cases belonging to the Valleyfield Coal Disaster[192.] in 1935, are of interest for, without exception, the victims suffered from symptoms referable to the cardiovascular system. Neurological sequelae were not in evidence. It is in such cases as these, that I feel that the percentage constituents of the noxious gas has a definite relationship to the after effects. Apart from carbon monoxide, complicating factors concerned in mine explosions are sulphur-dioxide from sulphur in the coal, acrolein from burning fat or oil, benzol and toluol.

There is no specific treatment for those showing cardiac disability due to gassing, for the elimination of carbon monoxide from the body in the routine treatment of the gassed victims, allows normal conductivity to proceed and irreversible processes to be kept at a minimum. To this I would add a corollary, i.e. that any man suffering from heart/

heart disease should not be exposed to concentrations of coal gas.

While dealing with the problems of vascular damage it is relevant to consider the process of coagulation. It is stated in medical text books that the blood remains fluid in the vessels following coal gas poisoning. This is certainly not a constant finding and experiments to show that coal gas diminishes or increases the coagulating power of the blood have failed,[68.] and Lewis believes that one may find fluid or coagulated blood and quotes the case of a 78 year old female and her grandson, killed in the same room by coal gas. In the first victim, the blood was fluid, in the second, coagulated.[132.]

Efforts to test this matter experimentally have failed[68.] because it has not been possible to poison animals sufficiently without killing them, over the long period of time common in fatal human cases. In cats, however, gassed fairly rapidly with pure carbon monoxide and coal gas, no changes were observed in blood coagulation.[74.]

Following the above lead, I removed blood for coagulation time from all patients admitted suffering from coal gas poisoning; their carboxy-haemoglobins varying between 5% to 55%. In no case did it differ from the physiological normal.

As none of the patients were suffering from prolonged gas poisoning the problem of polycythaemia and/

and increased viscosity does not enter this discussion.

HYPERTHERMIA.

The neurological signs reported, following gas poisoning vary greatly both in degree and type; many descriptions of isolated instances of unusual lesions have been noted. Different individuals react in various ways to the general anoxia and allied toxaemia, to which all parts of the body are subjected to, in greater or lesser degree. Damage may thus occur to the heat regulating centre in the brain, causing either a fall or rise in body temperature, depending on the deviation from normal of the 'thermostat'. Frequently preceding death in gas poisoning there has been a sudden elevation of temperature to 104F. - 106F. [83.] - "a temperature of 105F. forecasting a grave prognosis". However, Marthen [194.] & Benson [22.] reported cases of hyperpyrexia taking place during the recovery phase. The case of W.W. deserves mention in relation to this. He was a post-encephalitic Parkinsonism of many years' duration who attempted to commit suicide by gassing. He was agitated and garrulous on admission to hospital, with a carboxy-haemoglobin of 35%. This had fallen to 5% by the following morning. He was afebrile on admission but the following day his temperature rose to 106.5°F. and within two to three hours reverted to 100°F. During this attack he felt perfectly well and a careful examination revealed

no/

no new signs apart from his dry, burning hot skin. Following this episode he made an uneventful recovery.

The very fact that hyperpyrexia may take place in the recovery phase is, in my opinion, against anoxia being the sole injurious agent to the medullary centre; in the case of W.W. his carboxy-haemoglobin was 35% on admission and fell rapidly to 5% within 18 hours - anoxia was not only slight but short lived. Secondly, rather than develop new symptoms, it would have been thought that his already embarrassed basal ganglia would have suffered further damage. After 14 months, there is as yet, no sign of this happening and he is continuing at his work.

To account for these sporadic cases, two theories can be postulated:-

(1) a previously damaged area in the medulla which succumbs rapidly to further traumata.

(2) the constituents of the inhaled gas form the arrow-head striking through defences already breached by anoxia - similar to the action of benzol in exhaust gas poisoning.

ALIMENTARY SYSTEM

Without exception all cases of coal gas poisoning on admission to Edinburgh Royal Infirmary, suffered from severe nausea and vomiting. Victims of poisoning, whether it be acute or chronic, do suffer from this temporary upset. It occurred whenever the carboxy-haemoglobin was 10% or over,

and/

and is in keeping with results of American groups. Glaister and Logan mention that derangements of the digestive tract are common in industrial gas poisoning, with nausea and vomiting and more rarely diarrhoea. According to Hirt, all men concerned in the gas producing industry suffer from affections of the stomach, in his opinion, produced solely by constant inhalation of small amounts of coal gas. This was, of course, in 1910 and the improvement in industrial health can be gauged by the relatively few cases which are notified to the Public Health Authorities.

Drinker[65] quotes only one case - that of a garage worker whose abdominal symptoms so resembled duodenal perforation that he was admitted to a surgical ward. His carboxy-haemoglobin was 5%. He had had daily exposures to this small concentration and had suffered from the effects for several weeks. His symptoms subsided on removal from the fouled atmosphere.

In this series of cases two persons suffered from severe alimentary symptoms:-

> Mrs. B.C. aged 68, was overcome by fumes from a leaking gas pipe but, before collapsing, was able to summon assistance. Her carboxy-haemoglobin was approximately 20%. She made a rapid recovery, following the usual nausea and vomiting and lack of appetite, and was discharged, though still without appetite. Within ten days she developed nausea, vomiting, diarrhoea and "cramps" in the abdomen. This lasted for three days. Her appetite gradually improved/

improved during the succeeding weeks and she has remained symptom-free ever since. There was no evidence of any dietary indiscretions or of food poisoning.

Mr. P.G. following accidental gassing, suffered an acute exacerbation of his duodenal ulcer which had been treated successfully 7 years previously. This was the worst attack that he had ever experienced. His pains were accentuated, for a concomitant nausea prevented his eating food. There was no evidence of haematemesis and melaena and symptoms subsided in 4-5 weeks. He had no further dyspepsia.

The emotional factor in the above case might well have been the trigger mechanism for firing the new attack. It is possible that either the vascular disturbance caused by anoxia, similar to that in the brain, might have acted on a poorly nourished mucosal epithelium, or the exacerbation may have been caused by the methane or hydrocarbons in the coal gas.

Beck[19] and Sutor quote two similar cases which simulated, to all intents and purposes, gastric ulcer. When hospitalised and removed from the vicinity of a defective gas heater, they became symptom-free.

McNally[141] with wide experience, says that in the acute gas poisoning diagnoses have been made of food poisoning, and diabetes, many cases having persistent vomiting with coma and convulsions. Even in the chronic stage, the symptoms are described as loss of vigor, coated tongue and alterations in digestion.

The/

The fact that anoxia can cause a disturbance of the neurovascular mechanism could account for cardiospasm and pylorospasm, but as Drinker[65] says "these symptoms will not be seen so frequently in patients who have had a prolonged asphyxia".

Meyer[157] put gastro-intestinal disturbances as low as 24% in 50 garage men who were under observation and yet headache was seen in as many cases as 74%.

Hirt's[117] cases are in full agreement with my own; the common factor in all these cases of gas poisoning is carbon monoxide, which is obviously not, therefore, the sole culprit; the differing factor must be one or more of the constituents of the noxious gas. I would, therefore, postulate that the variability in the alimentary symptoms will depend, not so much on individual susceptibility, but on these other constituents.

Henderson,[108] whilst experimenting with dogs, noted that the animals subjected to pure carbon monoxide suffered neither from nausea or vomiting, whereas when coal gas was used with air, lack of appetite and vomiting were constant features.

Once again the fact is thrust upon us that there must exist in coal gas more than one agent detrimental to living tissue.

POST HOC ERGO PROPTER HOC.

There is nothing more demoralising than the unjust settlement of compensation. It leaves bitterness in its wake and opens wide the door to neurosis. I have presented in previous chapters victims of coal gas poisoning who, failing to recognise or choosing to ignore the danger under which they worked, find chronic ill health forcing them into unemployment.

Sequelae resulting from gas poisoning, may be masked for long periods - in some recorded cases as long as fifteen years. This time factor in the clinical manifestation of Parkinsonism and allied myostatic and psychomotor phenomena is unexplained. It is most readily demonstrated following pallidal and nigral lesions[32.] regardless of aetiology and was only emphasised as recently as 1930.

In this series the greatest number of sequelae occur in the ever increasing accidental group. It is important therefore that all possible hazards in connection with coal gas be reduced to a minimum. This can be done in two ways -

(a) by the use of foolproof distributing apparatus.

(b) by reducing the toxicity of the gas.

That carbon monoxide has toxic properties apart from its anoxic effect, has remained a controversial subject for many years. From the clinical and experimental material presented, it is evident that long periods of/

of exposure to minimal concentrations of coal gas without loss of consciousness, can lead to irreparable damage to the central nervous system and I believe that the hydrocarbons contained in coal gas are responsible for this effect. The shorter and sharper attacks with high concentration of coal gas produce sequelae which in no way differ from other agents causing anoxia. In these cases, I believe that carbon monoxide contained in coal gas blocks the haemoglobin radicle. This latter argument found confirmation not only in coal gas poisoning but in poisoning from cyanides, barbiturates etc. At post mortem, cases showed bilateral arterial thrombosis in the recurving pallidal branches supplying the globus pallidus, with an adjacent small dorsal strip of the internal capsule supplied by the same branch likewise involved. Dogs, however, exhibit none of this arterial meandering, yet their globus pallidus suffers similar trauma.

Is carbon monoxide then purely an asphyxiating agent by virtue of its haemoglobin blocking power? Not only does this latter experiment refute this, but Haldane showed toxic changes experimentally in animals and in seed germination where no haemoglobin was present. Killick made the study of carbon monoxide even more complex by showing very convincingly both in animal and human experiments that the clinical impression of acclimatisation to carbon monoxide was a reality; that in some way carbon monoxide

was/

was dealt with by the body with insufficient compensatory increase in the red blood count or oxygen carrying power to account for this phenomena. It would seem apparent however that in humans the toxicity of carbon monoxide is overshadowed by its anoxic effect.

Experiments both in animals and in tissue culture show increased toxicity to coal gas in comparison with carbon monoxide. The alimentary upsets in dogs with coal gas is analagous to cases of human gassing, never occurring when pure carbon monoxide is used. It is also a fact that red blood cells in animal and in human blood show increased fragility when exposed to coal gas, yet no effect was produced with pure carbon monoxide.

Finally, I have presented clinical and pathological observations on coal gas victims and in the preceding chapters have shown the vast difference between sequelae of the "slowly gassed" and those of the "quickly gassed". These sequelae affecting soma and psyche respectively are clinical proof of the existence of the double aetiology underlying coal gas poisoning.

(1) by anoxia

(2) by the toxic effect of its other constituents; these factors being complementary to each other.

Sequelae depend entirely on the rapidity of concentration and the duration of exposure to the coal gas. Experiments were recently performed with/

with radio-active carbon monoxide where it was demonstrated that the latter molecule showed a temporary storage in the liver; this same method I feel, may well have to be applied to the various constituents of coal gas before we may fully determine the method by which they produce their effect.

Until this time is reached, it will remain necessary to treat all victims of coal gas poisoning vigorously on the journey to hospital when the carbon monoxide concentration and the anoxic effects are at their height. In hospital, complete carbon monoxide elimination should be achieved in the shortest space of time, the devitalised tissues being protected from infection by the antibiotics. The success of this treatment is seen in the low mortality rate achieved in the last few years.

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